A RESISTANCE TIDE GAUGE

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by

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ABSTRACT

The design, construction, calibration, and field application of a simple resistance-type tide gauge are presented. The gauge measures coastal water level in relation to an elevation reference. A summary of previously available tide gauges is made with advantages and disadvantages noted.

The gauge sensor consists of a high resistance wire within a mercury-filled capillary. The mercury level in the capillary is pressure-linked to the sea water column and responds to changes of water level over a wide period range. The mercury column height changes the current-conducting length of the resistance wire in the capillary. The change in resistance is, therefore, linear with column height. The resistance element forms one arm of a Wheatstone bridge.

Laboratory evaluation and calibration are described. Recorded field observations of the resistance gauge are compared to the record of a "standard" tide gauge at the same location.

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Particular acknowledgment is extended to Mr. Frank Abbe of the Naval Postgraduate School Machine Facility for his experience and skill in transforming design layouts into a finely machined prototype gauge.

1. Introduction.

The tide measuring devices currently used to record coastal sea level fall into two categories: those which are self-registering and those which require observer presence to record tide data.

In the first category, there are three tide gauges presently in use. The "standard" tide gauge, or self-registering marigraph, is most commonly used at "primary" tide stations. It operates unattended, but in practice it must be serviced each day to insure proper operation. The "standard" gauge basically consists of a tide well, a system of wire and pulleys, and a recorder. The vertical motion of the float within the well is transmitted by the wire system to a stylus that inscribes the record on a rotating drum of paper. The wire and pulley system also supplies the power to rotate the recorder drum while a spring-driven clock records time. The size and mechanical complexity of the system requires the gauge to be permanently installed. Generally, the gauge is mounted on an existing structure such as the piling of a pier where the wire and pulley system can be attached to rigid members. Many difficulties may arise during operation including: broken or tangled wire, clock failure, torn paper, failure to trace, and hour-mark failure.

The accuracy of the "standard" gauge is a function of the tide well, its float, and the counterpoise of the system.[1] The gauge error is determined by the equation:[1]

$$e = 2.15\ W/d^2 \text{ (inches)},$$

where W is the weight in ounces required to actuate the mechanism, and d is the diameter of the float in inches. Therefore, the larger the float diameter, the greater the accuracy. Common float diameters are on the order of 8 to 12 inches.

Response of the "standard" gauge is dependent on the ratio of the cross-sectional areas of the water inlet to the well, or orifice, and the tide well. If the orifice area is denoted by a and the tide well area by A, by applying Toricelli's theorem[1] an equation for the rate of rise of water in a well in response to a change in sea level outside the well is:

$$\frac{dh}{dt} = \frac{0.6a}{A} \sqrt{2gh}$$

where g is the gravitational acceleration, and h is the water level difference. Using this relationship, the a and A can be adjusted to yield the desired response, keeping in mind the dependency of the gauge accuracy on the well diameter.

The overall accuracy of this type tide gauge is ± 0.1 foot. The cost of the equipment is approximately $1500, excluding site preparation.[2] For long period accurate recording of sea level, the "standard" tide gauge remains the most popular instrument. However it suffers from many limitations, one of the most important is the lack of portability.

The "portable" tide gauge is essentially of the same design as the "standard" but has the recording mechanism located within the tide well. The recording arrangement is spring-driven, operating for a period of eight days. The accuracy of this gauge is about ± 0.1 foot and the price is approximately $660.[3] Installation requires mounting of the tide well to a fixed member such as a piling. The "portable" is in general use, primarily employed at remote stations for short time periods.

The Canadian designed "Ottboro" tide gauge is portable and is also used in areas where the erection of a "standard" gauge is financially or physically impracticable. This gauge responds to a pressure differential created when the sea water column changes, exerting a pressure change upon a diaphragm that in turn transmits the change pneumatically to a shore recorder. The recorder and clock are spring-driven. The stylus is driven by the air pressure via mechanical linkage. The sensor assembly may be mounted on a permanent structure or anchored on or near the bottom. Due to the fact that the pressure change is transmitted via a capillary tube to the recorder, the distance between the sensor and the recorder is limited generally to 400 feet.[4] The accuracy of this gauge is about ± 0.25 foot and the cost approximately $200.[3] The primary difficulty encountered in the operation of the "Ottboro" is the malfunction of the pneumatic link. Air leakage and/or water intrusion may occur about fittings or at points in the submerged tube.

The U. S. Naval Hydrographic Office concluded "the portable tide gauges currently in use by this office are satisfactory and fulfill most of the present need."[3] However, the following recommendation was made: the possibility of transmitting measurements from one or more tide gauges to a central collection point several miles away should be investigated.[3]

A common tidal problem exemplifies the need for a remote sensing, high resolution tide gauge, as well as displaying the limitations of present equipment. Consider an irregular basin of constant depth open to the ocean as depicted in Figure 1. The water level will oscillate in a variety of modes in response to the various forcing functions. These modes will depend on the driving forces and the size and shape of the basin. The problem is to describe these modes over the basin. Water level recordings at several points in the basin are required to treat this problem. The size and remote location, if applicable, of this hypothetical basin precludes monitoring of the various records by a single trained observer. However, by transmitting recorded data to a central point, the gauge records can be simultaneously compared for malfunction.

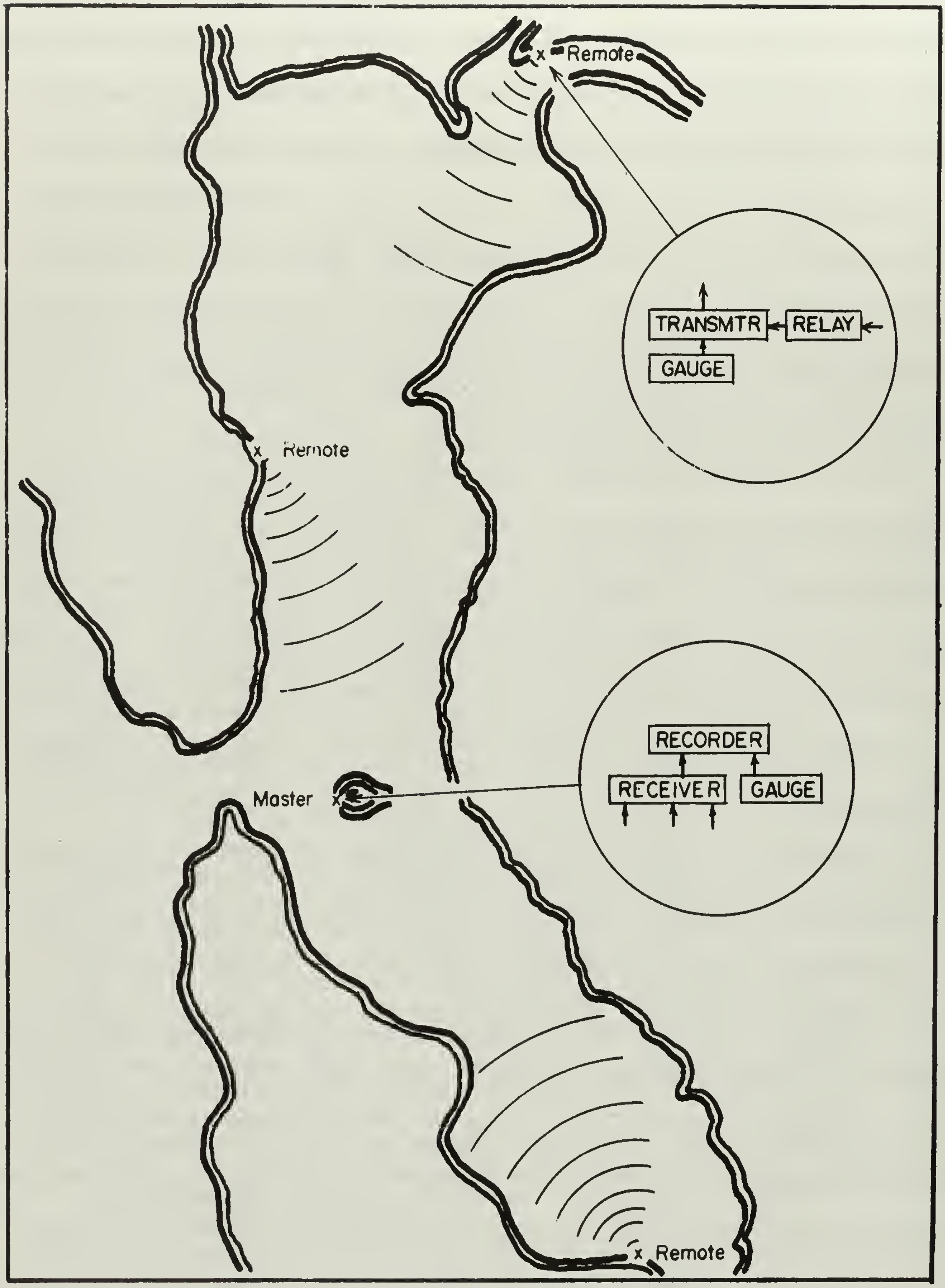


FIGURE I HYPOTHETICAL TIDAL SITUATION

Another aspect of the installation of existing gauges, and in particular the "standard" gauge, is the susceptibility of the gauges to abnormal land and water motion in seismically active areas. For example, "the combination of violent earthquake shaking, and battering by earthquake-generated waves of one form or another, left south-central Alaska without a single operative recording tide gauge," during the earthquake of March 27, 1964.[5] This exemplifies the requirement for a gauge that will withstand the seismic effects. Gauge damage occurs either by the translational component of the generated waves, in which case the gauge or its mounting is destroyed or damaged, or by the rapid and extreme vertical movement of the water level. Therefore, a gauge that is located on the bottom has an excellent opportunity to continue to operate and to record the environmental changes.

Therefore in summary, the following conclusions are formed:

1. The "standard" tide gauge is used at "primary" stations only.

2. The portable tide gauges presently in service are satisfactory but require permanent or semi-permanent mounting.

3. The employment of mechanical systems of the "standard" and portable gauges limits sensor response.

4. There is a requirement that future tide gauge design and development must include the consideration of the extraordinary forces encountered in seismically-active areas.

5. There is an acute need for multi-sensor networks which cannot be met with existing tide gauges.

Remote recording tide gauges present several design problems but must satisfy the following criteria: be highly mobile, as accurate, and as reliable as present gauges; be inexpensive, electrically operated, and have the ability to transmit and relay data.

2. Design and Construction

DESIGN. A resistance gauge, directly measuring a liquid level, satisfies the criteria of low cost, simplicity, electronic compatibility, and response. The simplest gauge would consist of a resistance sensor where output would be proportional to the water level. A fixed staff with two uniformly spaced bare wires, vertically oriented and connected to a power supply and indicator, could be used. The sea water level completes the circuit, and the length of unwetted wire determines the resistance of the circuit. This simple resistance gauge allows the elimination of mechanical drives and linkages. It is simple, inexpensive, and compact. However, environmental effects such as wave force, fouling, and corrosion reduce the usefulness of this simple design.

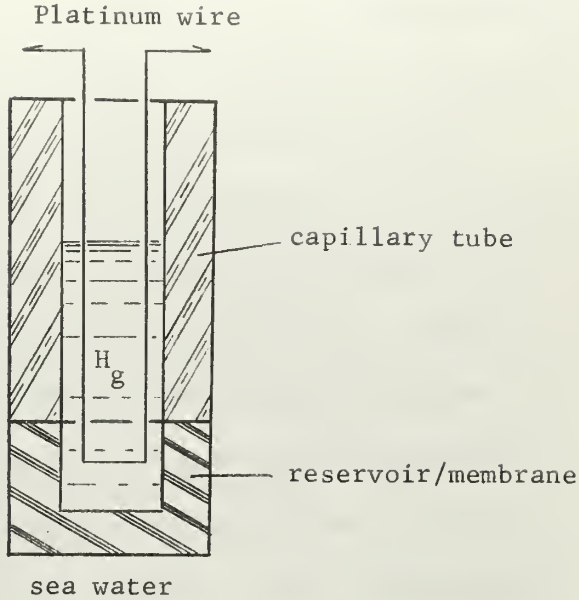
Many difficulties must be overcome in the design of a resistance tide gauge for use in sea level measurement. The most common problem is the environmental effect on the sensor. Corrosion occurs particularly in the area of stress. In addition, satisfactory high resistance wire has a low tensile strength and must be protected from dynamic water forces. Fouling can always be expected on surfaces exposed to sea water. These difficulties can be reduced by removing the wire from contact with the sea.

Removal of the conducting wire can be accomplished by enclosing the wire in a mercury-filled tube, using the theory of manometry as shown in Figure 2.

FIGURE 2

SENSOR

CONFIGURATION



In order to completely isolate the wire from sea water contact, a membrane must be placed between the two fluids. Since the density contrast between the mercury and water is large, the tube length can be reduced by the ratio of their densities. Mercury has a density or weight ratio of 13.236:1 to sea water of density 1.027 grams per cubic centimeters (sea water of salinity of 36 parts per thousand and temperature of 14 degrees Centigrade). For example, a 12 inch mercury column change is equivalent to a 13.24 foot sea level fluctuation. Therefore, in addition to removing the wire from the sea water, the use of a mercury column allows compaction of design. Furthermore, the vapor pressure is low and can be neglected as can the wetting of the wire for certain wires such as platinum.

Although tides are primarily a function of the gravitational attraction of celestial bodies, water level oscillations due to other forces are also measured. Among these forces atmospheric pressure and surface waves cause large tidal anomalies. However, changes in atmospheric pressure can be neglected if the mercury column is maintained at atmospheric pressure.

Wind-generated gravity waves cause water level changes over the gauge, both by the undulance of the surface and by the piling of water at the coast-line. The water level record will depict both of these phenomena. At a typical recording speed (1 inch/hour), the wind waves and swell will appear as a broad noiseband around the mean water level. On the other hand, water pile-up associated with waves appears on the record as a deviation from the predicted tide. When the water level change due to tidal phenomena is of primary interest, the surface wave action must be dampened or filtered from the record. This may be achieved mechanically by enclosing the mercury reservoir in a highly viscous fluid such as silicone oil, or by constructing an electronic filter.

The salinity and temperature can influence the output of the resistance gauge by changing the density of the column. These effects must be investigated. Increasing the salinity of the sea water, the mercury/sea water density ratio decreases and the mercury column will be displaced an increment higher. But, since a salinity change of 1 part per thousant (ppt) is approximately equivalent to a density increment of about .008 grams per cubic centimeter,[6] a change of 5 ppt will produce only about 0.06 foot change in measured tide level. Therefore, unless the instrument is situated in a region of extreme ranges of salinity, the effect of this parameter may be neglected.

Since the instrument will be fully immersed during operation, it is subjected to the fluctuating "in situ" water temperature. Temperature can affect the gauge in two ways. First, the resistivity of the wire is a linear function of the temperature. The temperature coefficient of resistance of a platinum wire is on the order of $2.5 \times 10^{-5}/^{o}C$. Since high resistance wire is used in this gauge, the relative resistance change for even a 10 degree Centigrade change can be neglected.

The second effect of temperature is that of the thermal expansion of the gauge components. The complexity of the gauge prohibits an explicit mathematical solution for the temperature response, and efforts to evaluate this in the laboratory have been unsuccessful. A qualitative investigation results in the following analysis.

The coefficient of thermal expansion of acrylic plastic is about $9 \times 10^{-5}/^{o}C$ and that of platinum wire about $8 \times 10^{-5}/^{o}C$. Such small values can only have second order consequences. The two components of significance are the mercury and the fluid surrounding the mercury reservoir, if the latter is used. The expansion of these components can be critical as mercury has a thermal coefficient of expansion of about $18 \times 10^{-5}/^{o}C$, and distilled water a coefficient of about $36 \times 10^{-5}/^{o}C$. If a volume of 50 cubic centimeters of mercury and a volume of 200 cubic centimeters of distilled water are used, a $1^{o}C$ change will produce a 0.25 centimeter height change in a .625 centimeter diameter mercury capillary. This is approximately equal to a water level change of 0.1 foot. Therefore, temperature control is critical as has been noted previously by Snodgrass.[7]

MATERIAL. Most of the gauge components were constructed of acrylic plastic for the following reasons: Acrylic is easily machined, readily joined, and has a good strength-weight ratio. Furthermore, this plastic is inexpensive and is resistant to sea water corrosion and fouling. The transparency of acrylic allows observation of the internal functioning of the instrument. However, most important, acrylic is not wetted by mercury as any loss of mercury by wetting the sensor tube will cause an error in the reading.

The sensor wire must be chemically inert to mercury and must have a sufficient resistivity to allow a resistance change equivalent to 0.1 inch of wire length to be resolved. In the prototype, a pure platinum wire of .003 inch diameter allowed this resolution. The resistivity of this wire is 6.67 ohms per foot. Platinum wire of up to 2500 ohms/foot is commercially available, but this extreme resistance was sacrificed for tensile strength.

A double loop of 6.67 ohms/foot wire is used in the capillary providing a resistance range of 0 to 20 ohms over the column length. The wire forms one arm of a Wheatstone bridge, supplied by a 1.5 volt dry cell battery. Only 2 to 3 milliamperes are required for the operation of the bridge providing an excess of 30 days of operation for a single dry cell.

A vinyl reservoir is used to hold the excess mercury not contained in the sensor column. Natural rubber, initially tested in the prototype, proved unsatisfactory because of its chemical reaction to the mercury. Damage to the reservoir is avoided by enclosing it in a fluid-filled bellows that also can be used to dampen surface high frequency oscillations. For the prototype, this system consists of a neophrene bellows containing distilled water.

CONSTRUCTION. Construction of the prototype was made within the design criteria. The constructed prototype is shown in Figure 3 through 7. Details of construction are depicted in Appendix I. The prototype (Figure 3) consists of four basic sections: housing, water chamber, sensor, and snorkel. The housing, (Figures 3 and 4), is an airtight cylinder that houses the sensor and electrical connections, separating the sensor from the sea. The water compartment is open to the sea water

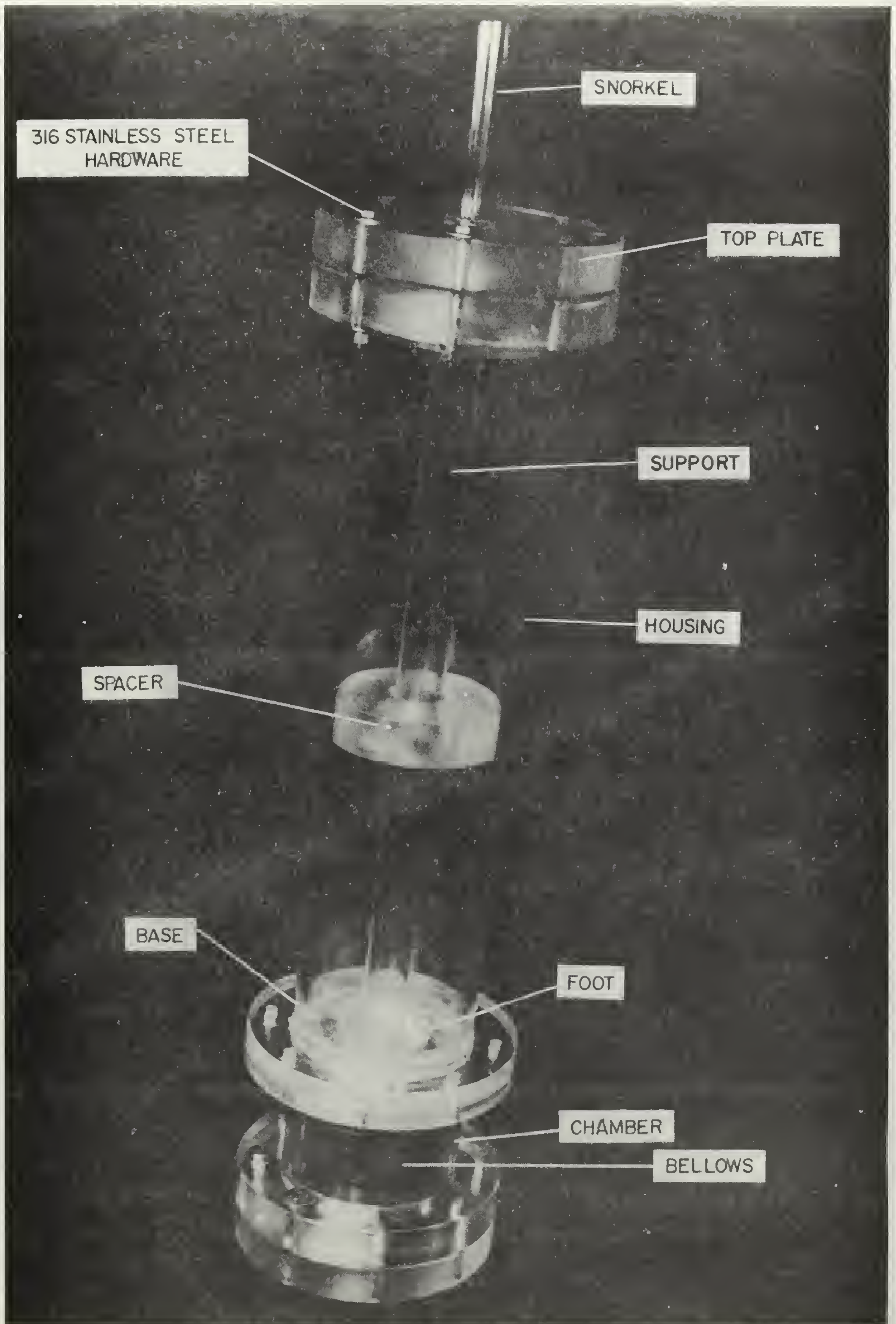


FIGURE 3 PROTOTYPE WITHOUT SENSOR ASSEMBLY

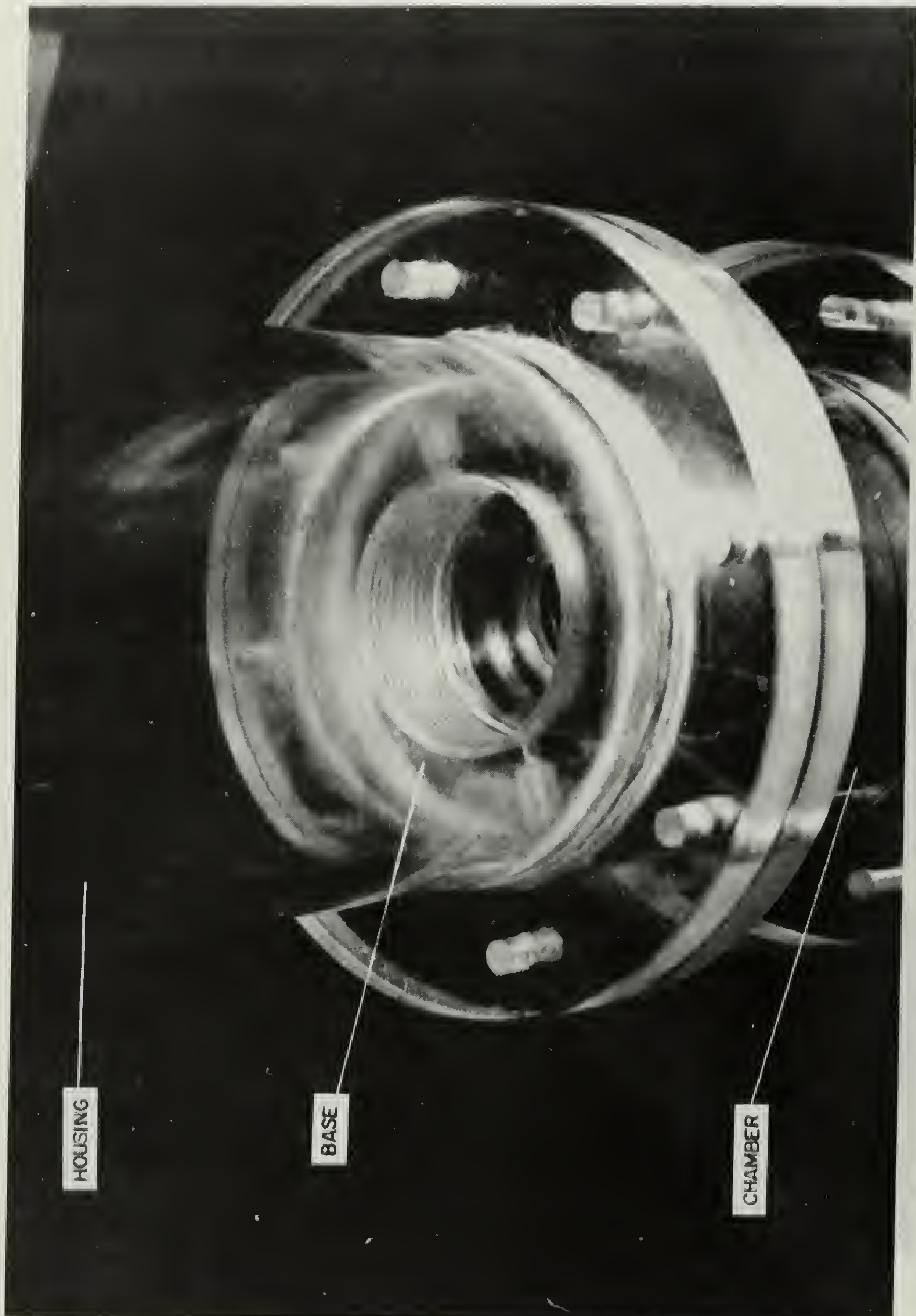


FIGURE 4 BASE DETAIL

via the orifice, (not shown). The snorkel maintains the venting of the mercury column to the atmosphere and contains the electrical connection between the surface recorder and the submerged gauge. These three sections are flanged and mated with #316 stainless steel hardware. Neophrene gasketing material is used at the flanges, eliminating leaks.

The sensor is more complex in construction. Initially, a single wire with terminals at each end was placed within the acrylic tube, but the precision craftmanship required and the difficulty of repair and/or replacement of the sensor made this design untenable. Therefore, a single wire, doubled by looping about a spacer at the bottom of the tube, was utilized. This was accomplished by the introduction of a Number 6-32 screw as shown in Figure 5. The wire is then separated by the diameter of the screw at the bottom and by a threaded Number 6-32 nylon key at the top. The nylon key, shown in Figure 6, in addition to separating the wire, is used to tension the wire. This arrangement not only simplifies the design but also doubles the resistance change per mercury level increment.

The neophrene bellows used in the gauge, shown in Figure 7, is manufactured for use in the Snodgrass Mark IX Wave Recorder.[8] The bellows and contained fluid protect the reservoir and can dampen high frequency oscillations of water level. Silicone fluid was initially selected as the internal fluid because of its high viscosity. The substitution of distilled water was made due to interaction of the silicone and mercury through the molecular lattice of the vinyl reservoir. The substitution did mean an expected loss of dampening.

The Wheatstone bridge is constructed with two temperature stable resistors (25 ohms) and a 25 ohm potentiometer. This potentiometer is used to balance the bridge at the midpoint of the range. Also

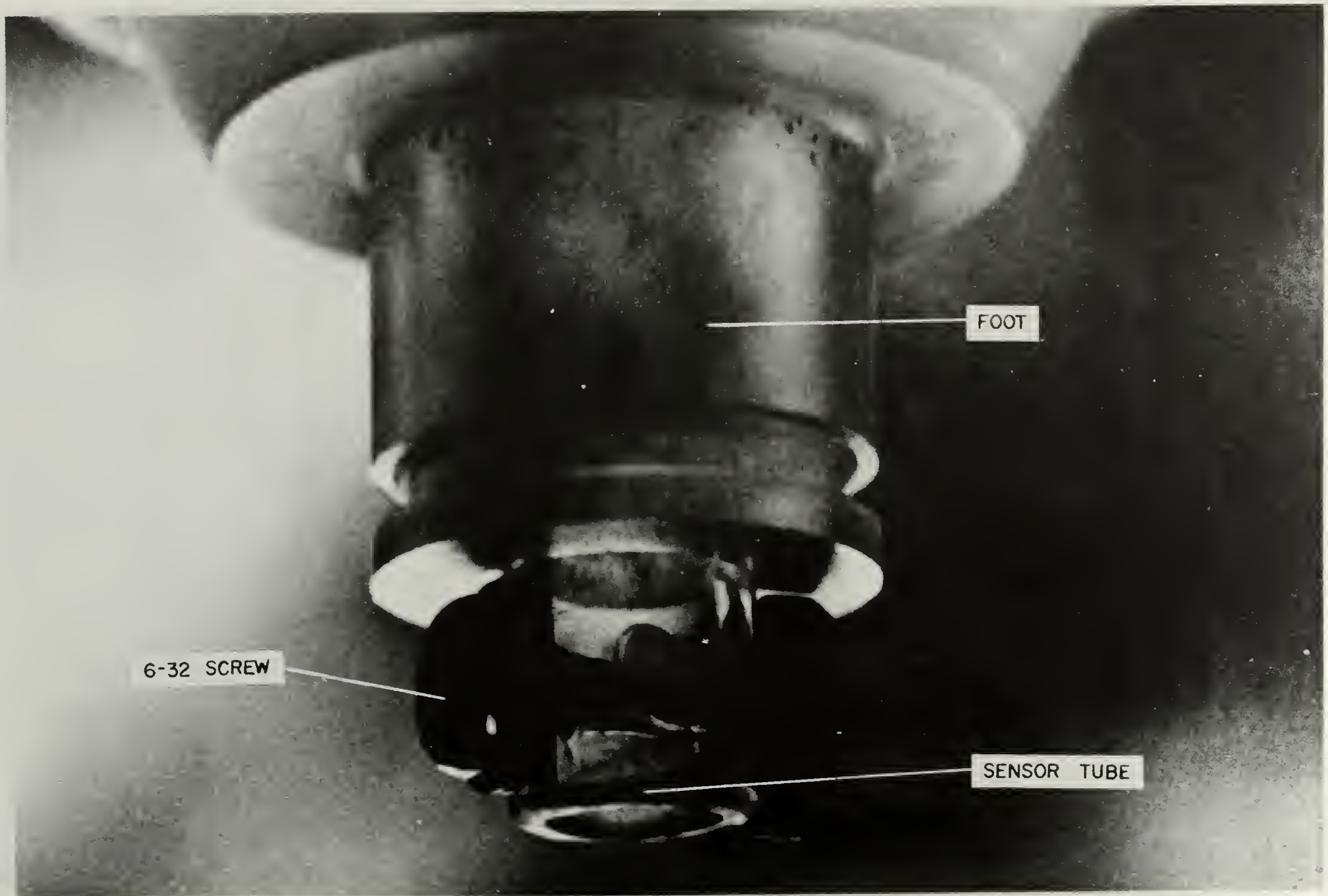


FIGURE 5 LOWER SENSOR ASSEMBLY

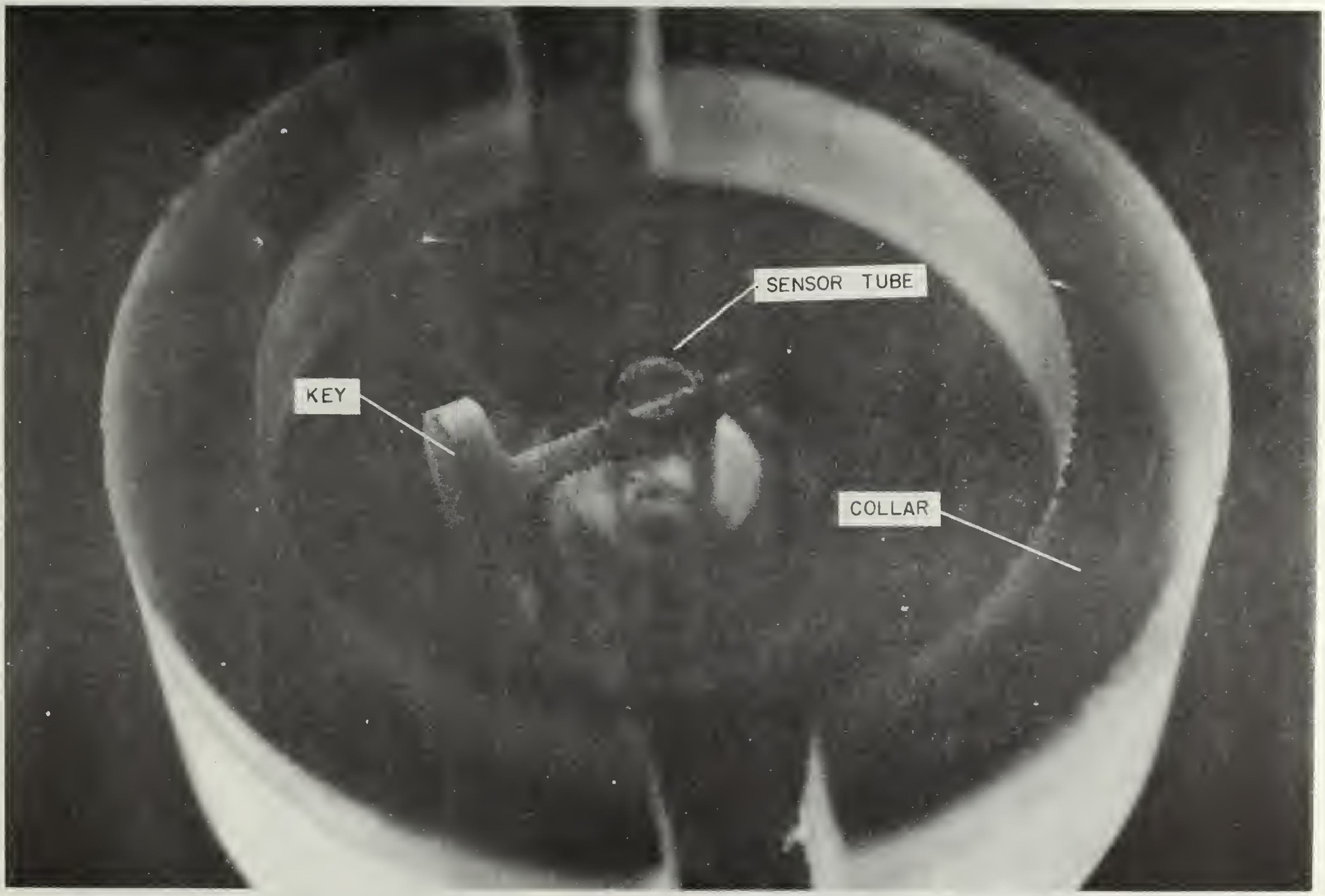


FIGURE 6 UPPER SENSOR ASSEMBLY

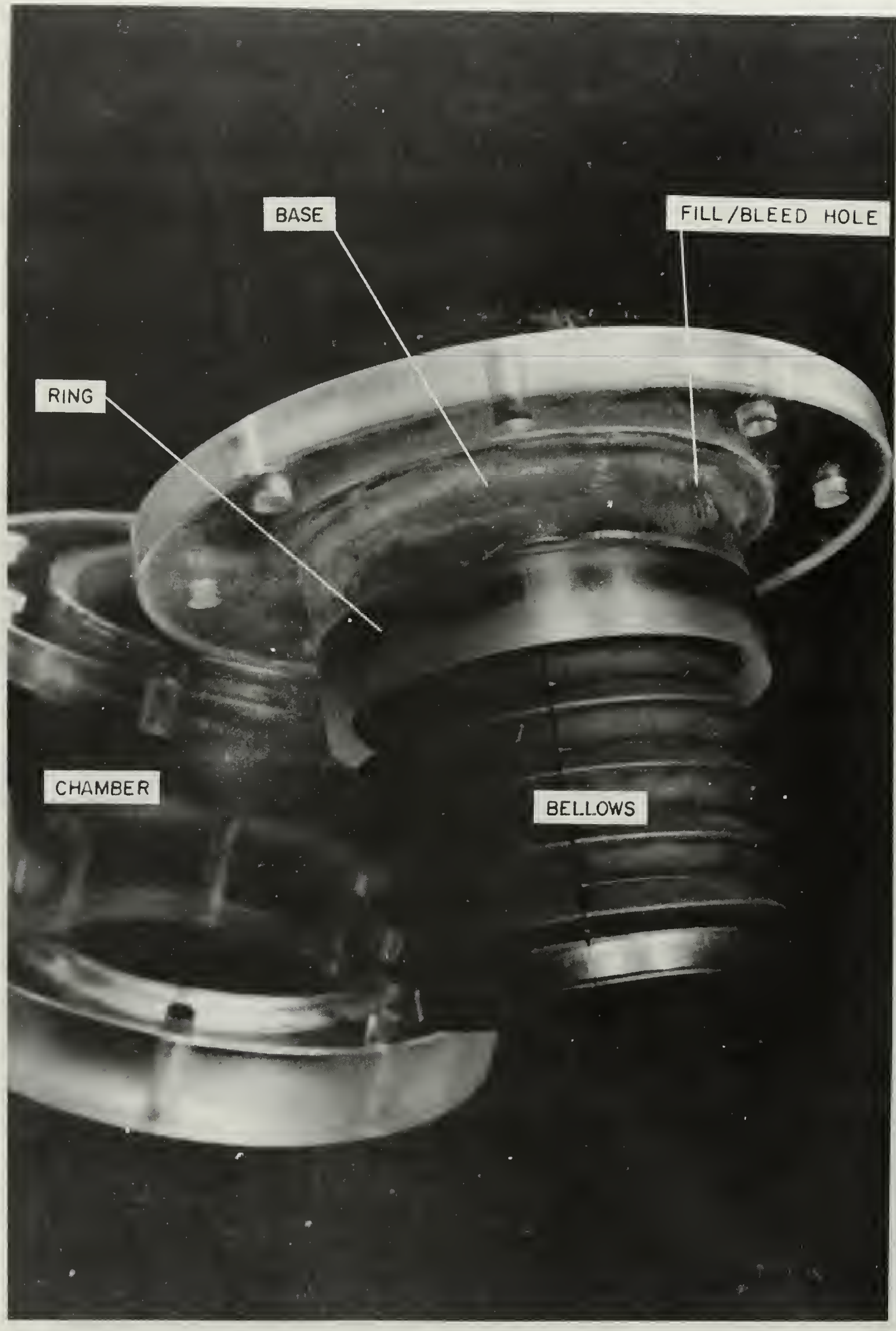


FIGURE 7 BELLOWS ATTACHMENT

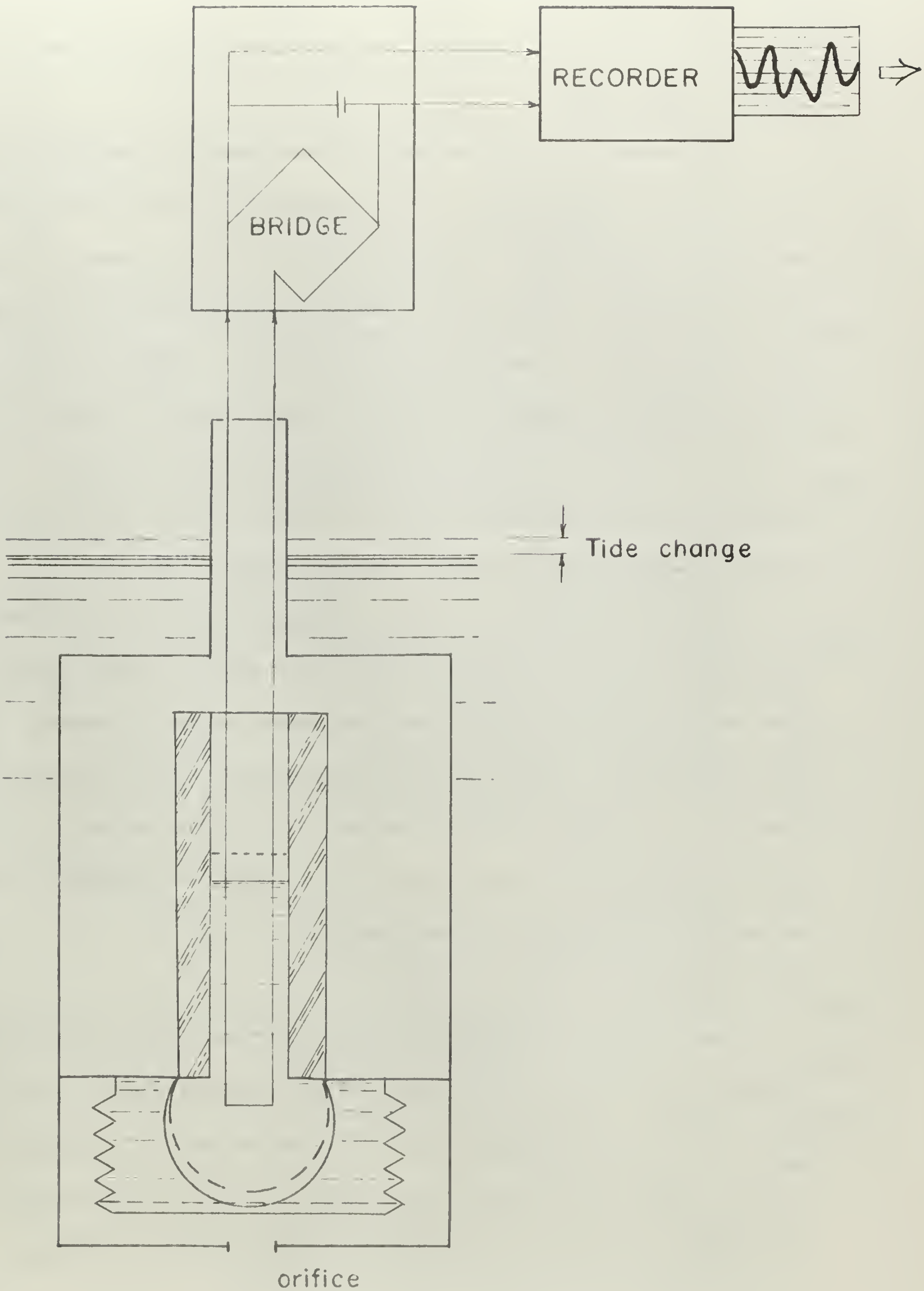


FIGURE 8

GAUGE OPERATION

incorporated into the circuitry of the bridge and power supply is a 5000 ohm potentiometer which enables the current to the recorder to be varied. Therefore, full scale deflection of the recorder can be used for any selected tide range.

The reservoir is filled with a known amount of mercury through the sensor tube. Extreme care must be exercised so that large globules of mercury do not directly impinge on the wire. Wire damage during filling can be reduced by straining the mercury through cheesecloth and placing the sensor about 15 degrees from the vertical. After filling, the reservoir is manually agitated to purge all air from the reservoir and column.

The bellows is placed in position, and then the sensor is inserted into the housing and secured into the base. Teflon pipe tape is used to prevent leaks via the machined threads of this junction.

The bellows cavity is filled through one of the two threaded holes in the base, shown in Figure 7, while the other remains open for bleeding. The drain plugs are inserted and the water chamber attached. Insuring that the lead-in cable is properly connected to the terminals on the sensor, it is strung through the snorkel, and the snorkel is attached to the housing. The surface end of the cable is connected to the bridge as are the power supply and the recorder.

3. Operation

The instrument functions in the following manner (See Figure 8): Movement of the water level generates a pressure change at the orifice, expanding or contracting the bellows, depending on the direction of the motion. The reservoir must also adjust to the new level, and therefore, the mercury column falls or rises linearily with the change.

The movement of the mercury column level changes the resistance in the sensor arm of the bridge. Increase in the mercury column height results in a decrease in the length of conducting wire and therefore a decrease in resistance. An accuracy equivalent to that of the "standard" gauge can be achieved if the mercury column can be measured to ± 0.1 inch. If the bridge is initially nulled, then a change in the mercury level unbalances the bridge, and a current proportional to the resistance change can be transmitted to a recorder. The gauge can employ any type of recording system although for this study a Model G 11 Varian strip chart recorder was used. The width of the recorder pen trace and the scale enables an observational accuracy of ± .01 foot of tide change.

4. Calibration

The prototype gauge was submitted to controlled testing and calibration. During laboratory testing gas pressure from a nitrogen cylinder was used in place of water pressure to actuate the sensor. For this reason, the orifice was tapped to accept a standard ½ inch pipe thread, and the water compartment was sealed with gasketing. The test configuration is shown in Figure 9.

A five foot mercury manometer provided the standard for the calibration tests. The gauge and manometer were connected in parallel so that the pressure introduced to the gauge was equal that applied to the manometer. Output from the gauge was measured by a precision Wheatstone bridge. The calibration was conducted over the entire range of pressure to be encountered in the field. Variation of the gas pressure is analagous to a changing water column height. The nitrogen pressure was stabilized at random pressure values within the test range, and the manometer and the bridge values recorded. Accuracies of these measurements are ± .005 ohms for the bridge and ± .02 inches of mercury for the manometer.

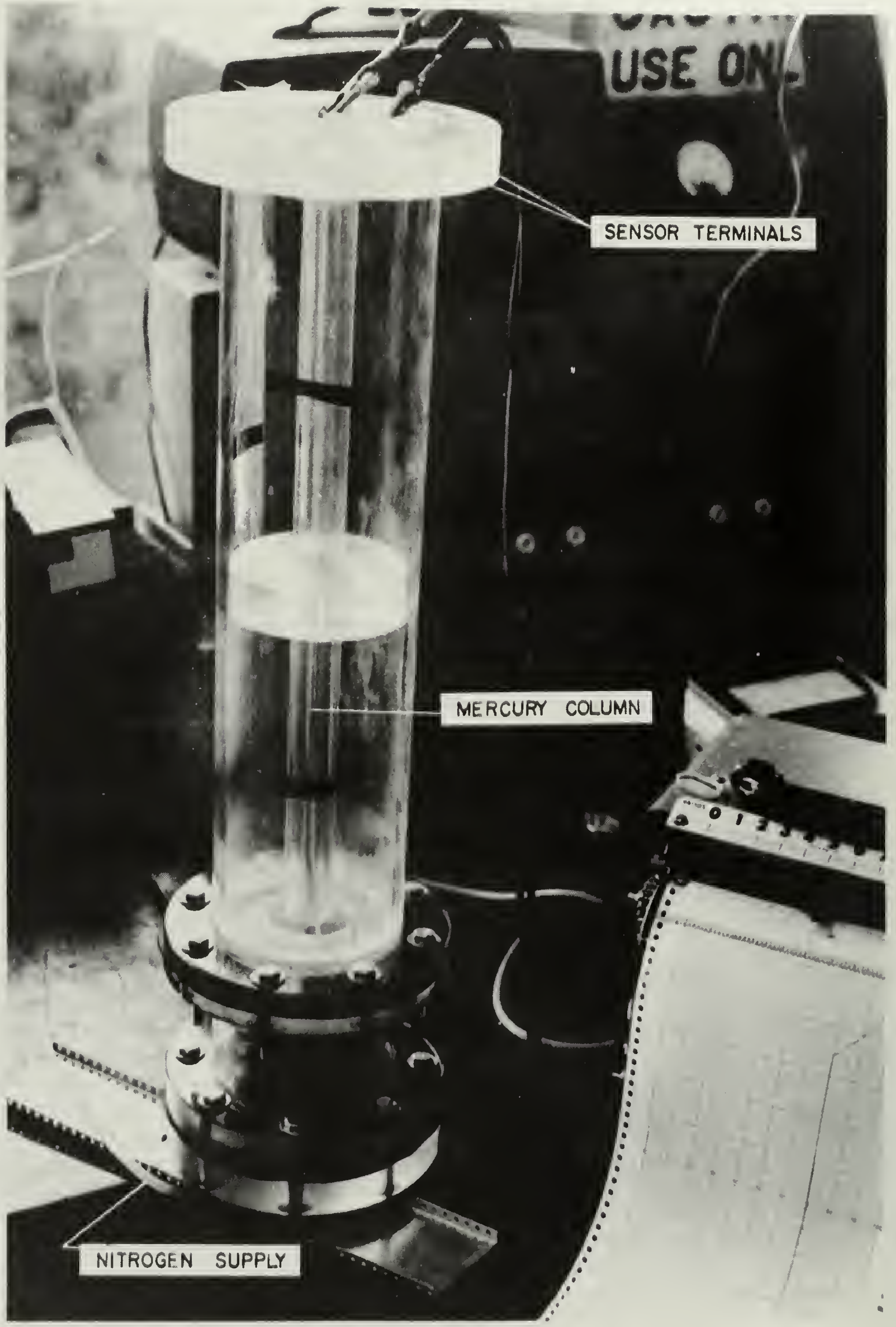


FIGURE 9 LABORATORY TEST CONFIGURATION

Two calibration runs were made, one before and one after the gauge was placed in the Monterey Bay for "in situ" testing. The data from Run #1, conducted prior to "in situ" testing, was evaluated using the least-mean squares line method.[9] The resulting equation was:

$$n = 24 \qquad Y = -0.9825\ X + 24.732$$

$$S = \pm\ 1.091 \text{ inches of sea water}$$

where X is the pressure in inches of mercury, Y, the resistance in ohms, n, the number of calibration points, and S is the standard deviation. The values of sea water height are based on the assumption that the density ratio of mercury to sea water is 13.236:1.

After "in situ" testing, Run #2 was conducted and evaluated under the identical method as Run #1, producing the results:

$$n = 10 \qquad Y = -1.0519\ X + 27.156$$

$$S = \pm\ 0.555 \text{ inch of sea water.}$$

Calibration data and evaluated least-mean squares lines are shown in Figure 10.

Individually, the calibration runs produced a standard deviation of less than ± 0.1 foot of sea water. Inspection of the two runs shows that the slopes of the lines are nearly equal but that the lines are displaced by an average value of about 1.66 ohms. Since the difference is explainable, below, the data can be combined to determine the best curve to use for the "in situ" test.

A third least-mean squares line was determined, utilizing data from both runs to find this best curve relating a resistance change to a water level change. In order to fit a single line to both sets of data, 1.66 ohms was subtracted from each resistance value of calibration Run #2. The combined data evaluation resulted in the equation:

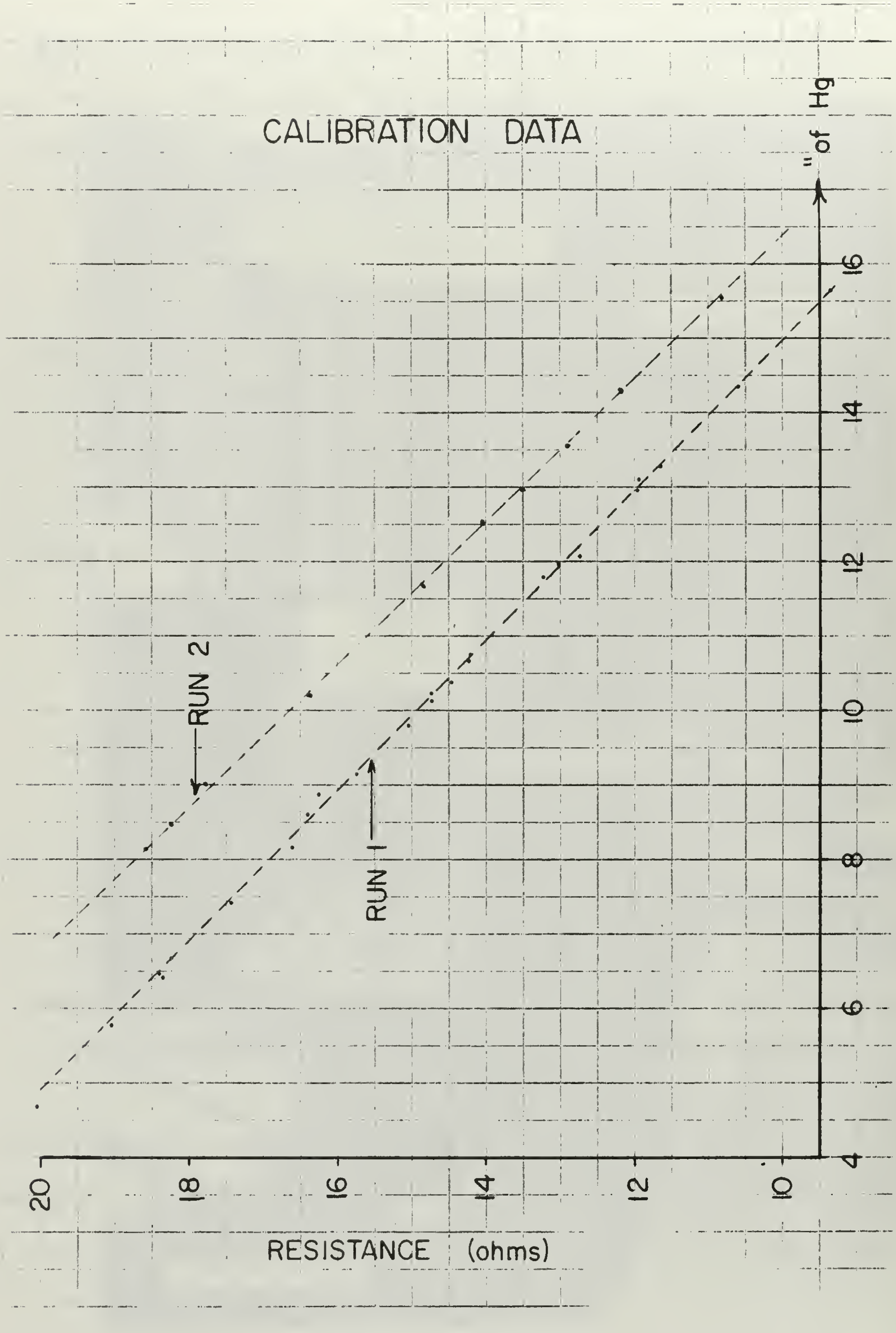


FIGURE 10 CALIBRATION CURVES

$n = 34$ $\quad Y = 0.999\,X + 24.90$

$S = \pm 1.494$ inches of sea water.

The difference between the calibrations, Run #1 and Run #2, of -1.66 ohms can be attributed to two factors: the change in the resistance of the lead-in cable, and bag expansion. The sensor resistance, including the lead-in cable measured after "in situ" testing, was 0.50 ohms higher than during Run #1. This is attributed to the soldered connections made during field installation.

The remaining 1.16 ohms are attributed to the stretching of the vinyl mercury reservoir. This is the total change over the period between laboratory calibrations. The way in which this expansion occurred over this period is not known. Only a first order approximation of the expansion prior to and during "in situ" testing can be made. The expansion is assumed to be linear function of the applied pressure. The weight of the mercury in the reservoir is equivalent to a water column of 2.3 feet of sea water. Expansion is determined by assuming the reservoir has a cylindrical shape and the weight of the mercury is concentrated on the base. Since prior to "in situ" testing the instrument was under several pressure states, the approximation must be made by weighting these pressures over the time in which they were applied.

The following is a history of the gauge and was used as input data:

		Gauge under pressure of:
Calibration Run #1	081200L April	> 5.0 feet of sea water
	081200L - 081800L	0.0 feet of sea water
"In Situ" Preparation	081800L - 091200L	1.0 feet of sea water
	091200L - 091600L	0.0 feet of sea water
"In Situ" Testing	091600L - 201300L	> 6.5 feet of sea water

		Gauge under pressure of:
Removal	201300L - 201500L	0.0 feet of sea water
	201500L - 201700L	0.8 feet of sea water
Calibration Run #2	201700L - April	> 8.9 feet of sea water

Expansion was neglected during the "in situ" testing and during time intervals when applied pressures were greater than the equilibrium pressure, i.e., 2.3 feet of sea water. The resulting average linear expansion of the reservoir was about 0.045 inch of mercury/hour. Consequentially, a first order approximation for correcting the reservoir expansion is the application of -1.12 feet of sea water to the "in situ" observations.

5. "In Situ" Testing.

The calibrated instrument was placed in the Monterey Bay during the period 8 to 20 April 1967. The purpose of the "in situ" test was to compare the outputs of the "standard" and resistance tide gauges.

The resistance tide gauge was mounted on the structure of Municipal Wharf #2, Monterey, California, at a depth of about 5 feet below MLLW. The gauge was located within ten feet of the "standard" tide gauge which is maintained by the Naval Postgraduate School. The proximity of these two gauges eliminates record dependence on location differences. The reference level of the resistance gauge was the lower plane of the orifice, which was 6.54 feet below Coast and Geodetic Survey (C&GS) MLLW datum.

The instrument was mounted and connected to the bridge and recorded as shown in Figures 11 and 12. Substituting two known resistances for the sensor, the recorder was setup to produce a 5 inch full scale deflection for 10 ohms, which is equivalent to 11.10 feet of tide range.

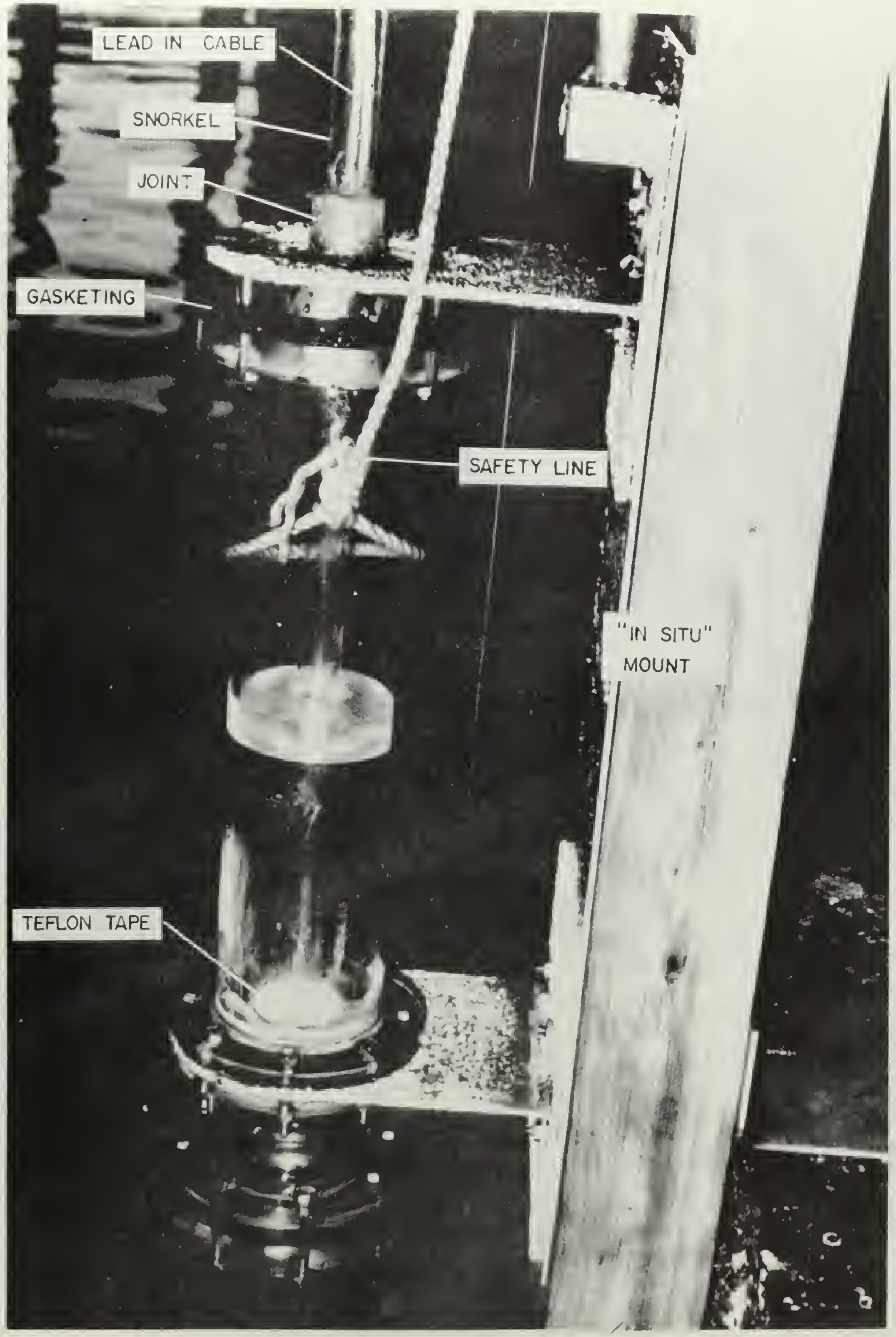


FIGURE II "IN SITU" TEST CONFIGURATION

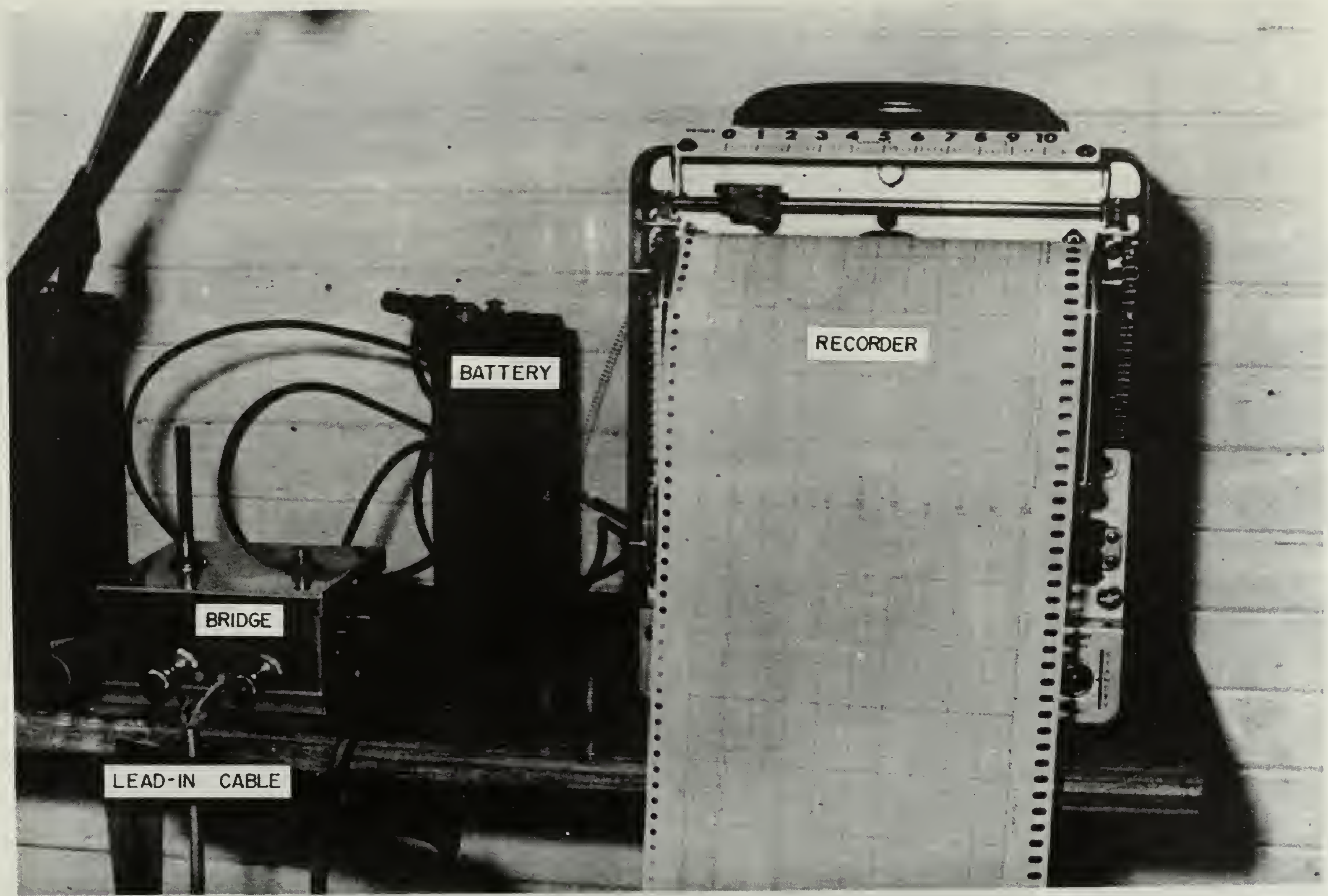


FIGURE 12 BRIDGE AND RECORDER SYSTEM

Interim checks were made for recorder drift during the "in situ" testing with the known resistances. The "in situ" test commenced for comparison purposes on 10 April 1967. The recorder chart transport was 1 inch per hour. The test was interrupted once at about 0607 P.S.T. on 13 April, for about a 30 minute period to change the orifice diameter from 0.5 inch to 0.125 inch.

6. Results.

The criteria established in Section 1 require the resistance gauge to meet the specifications of the "standard" gauge. In order to evaluate the degree to which the criteria are met, the record of the resistance gauge was compared to both the record of the "standard" gauge and the predicted tide levels. Examples of the records are shown in Figures 13 and 14. Records of the entire "in situ" test are on file at the Naval Postgraduate School.

Predicted tide heights were calculated at selected times from C&GS Tide Tables for the Pacific Coast.[10] The times selected were the times of high and low tides and selected values between these water levels. At these times, recorded heights were taken from the "standard" and resistance records.

Tide height was calculated from the resistance gauge record by the following calibration line:

$$Y = -0.999\,X + 24.90.$$

Using the conversion factor of 1 inch of mercury = 1.103 feet of sea water, and subtracting the gauge elevation from C&GS datum, the water level, H, (referenced to MLLW) is calculated by:

$$H = 1.10\,(24.90 - Y) - 6.54.$$

These values are then corrected for reservoir expansion by the subtraction of 1.12 feet.

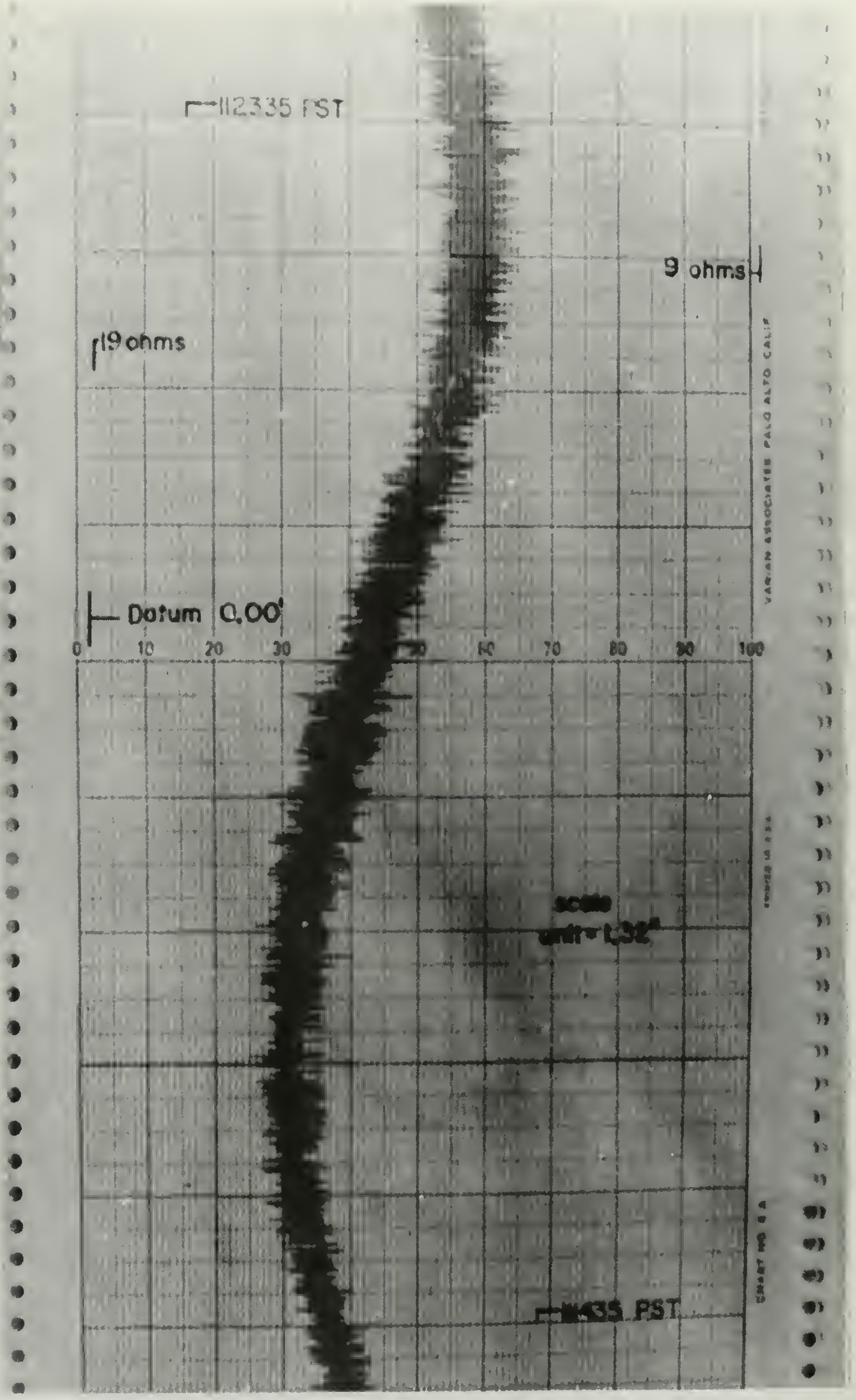


FIGURE 13 RESISTANCE TIDE RECORD

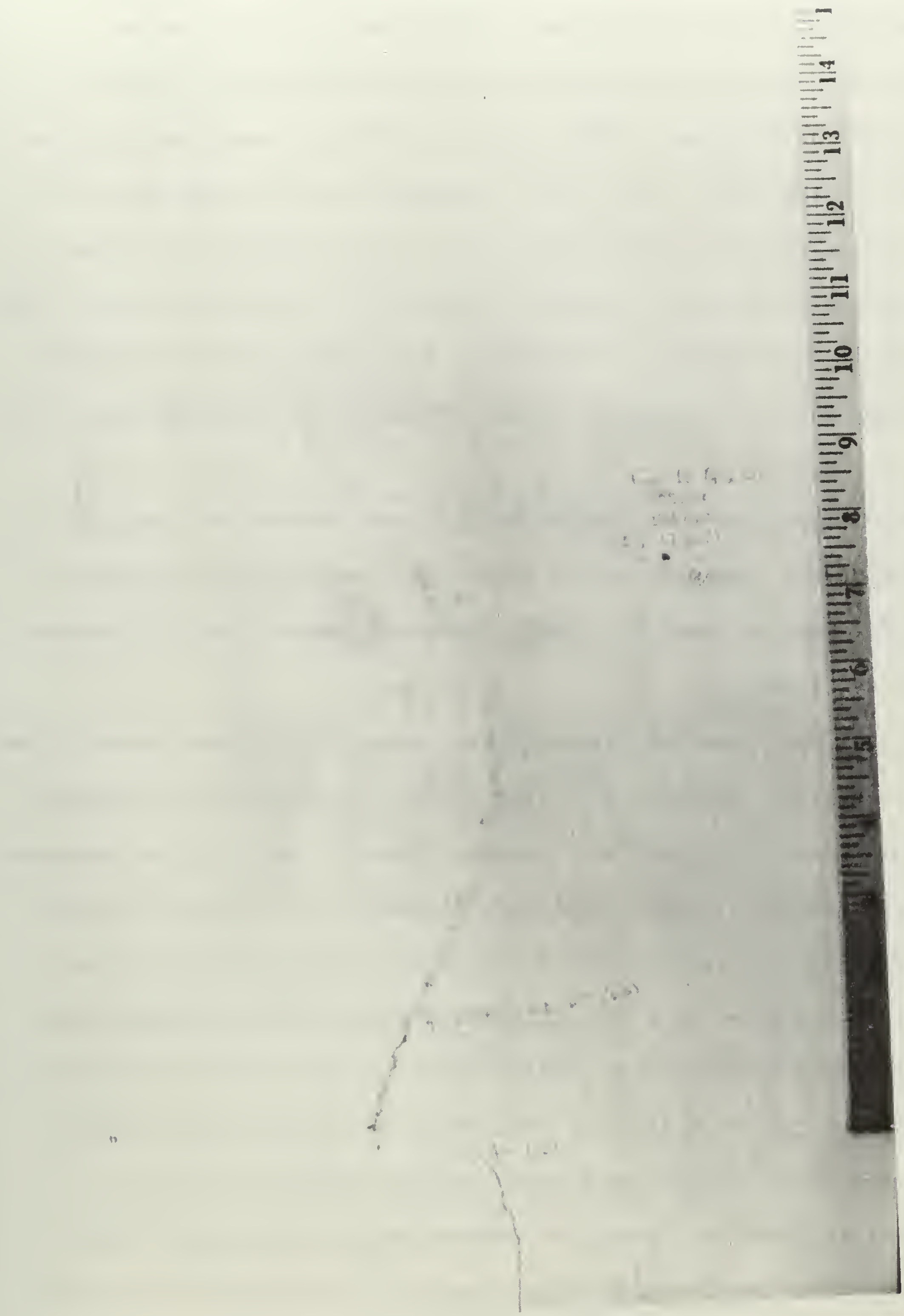


FIGURE 14 "STANDARD" TIDE RECORD

Selecting the predicted tide as a reference, predicted values were subtracted from the gauge records. The results are shown in Figure 15. Malfunction of the "standard" gauge during the comparison period is shown as a break in the "standard minus predicted" curve. Both the "standard" and resistance heights show a periodic disagreement with the predicted water level. This is not unexpected as predicted values do not consider the water pile-up due to wind and wind-generated waves, harbor oscillations, and many other factors which disturb sea level. In the case of the "standard", the largest disagreement occurs at higher high water and best agreement at times between lower high and higher low water.

Figure 19 shows a consistent disagreement between the two gauges, maintaining the same sign except at 112000L. The average magnitude of this difference is about 0.5 foot. There are several possible reasons for the deviation.

First, the datum for the resistance gauge is the lower plane of the orifice, measured relative to a tide staff. The tide staff is periodically tied into local C&GS bench marks. However, water column pressure is applied over the entire reservoir. Assuming that the mid-point of the reservoir best approximates the pressure application point, the deviation is reduced by about 0.3 foot. Secondly, the reference level was determined from the tide staff to an accurancy of about ± 0.15 foot. Therefore, the records from the "standard," which is surveyed to the staff, and the resistance gauge can only be compared to ± 0.15.

Finally, both the "standard" and resistance gauges record high frequency water level oscillations. Because of the greater sensitivity

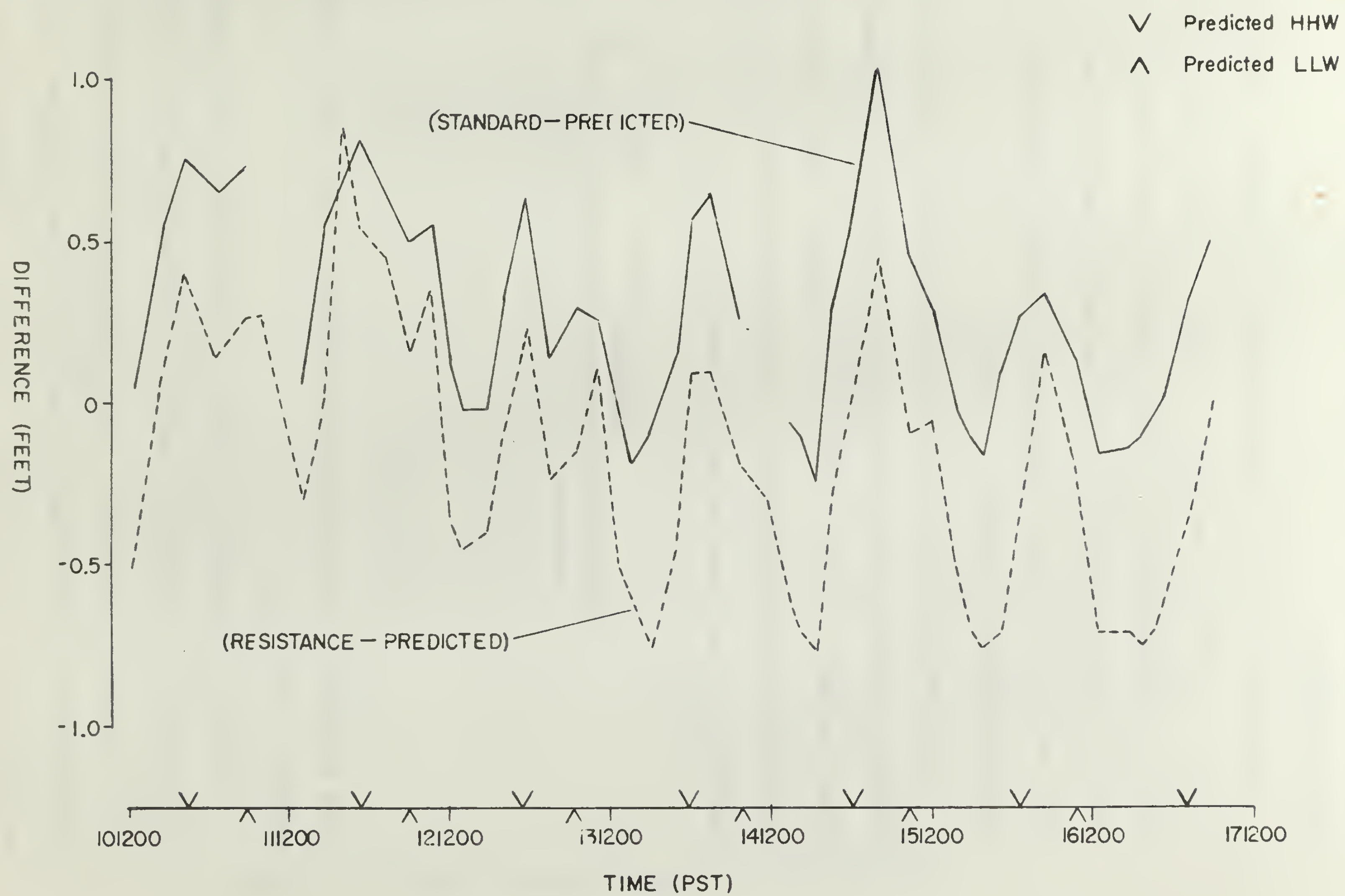


FIGURE 15 GRAPHICAL COMPARISON OF TIDE RECORDS

of the resistance gauge this "noise" band is much broader than the "standard" gauge noise band, causing some difficulty in determining the exact water level.

During the "in situ" testing period the bandwidth varied between 0.11 and 1.07 feet of sea water in width. The bandwidth is plotted in Figure 16. Although the resistance gauge is located within a pier structure, water oscillations from the Bay are present above the gauge. These oscillations have a dependency on the wave conditions in the Bay but are modified by the pier structure.

An investigation was made into the correlation between "noise" bandwidth and the environmental parameters most apt to influence the higher frequency oscillations.[9] The correlation coefficient, r, of bandwidth with the parameters of atmospheric pressure, tide height, wind velocity, and wave height are summarized below:

Parameter	r
atmospheric pressure	.44
tide height	.39
wind velocity	.33
wave height	.98

While parameters are significantly correlated, wave height has the strongest correlation.[9]

Values of atmospheric pressure and wind velocity were obtained from the Naval Air Facility, Monterey, California, which is located about two miles from Wharf #2. Wave data were available for part of the observation period from the Snodgrass IX Wave Recorder situated off Del Monte Beach in about 26 feet of water at a distance of about 1500 yards from the resistance gauge. Wave heights are modified by the pier

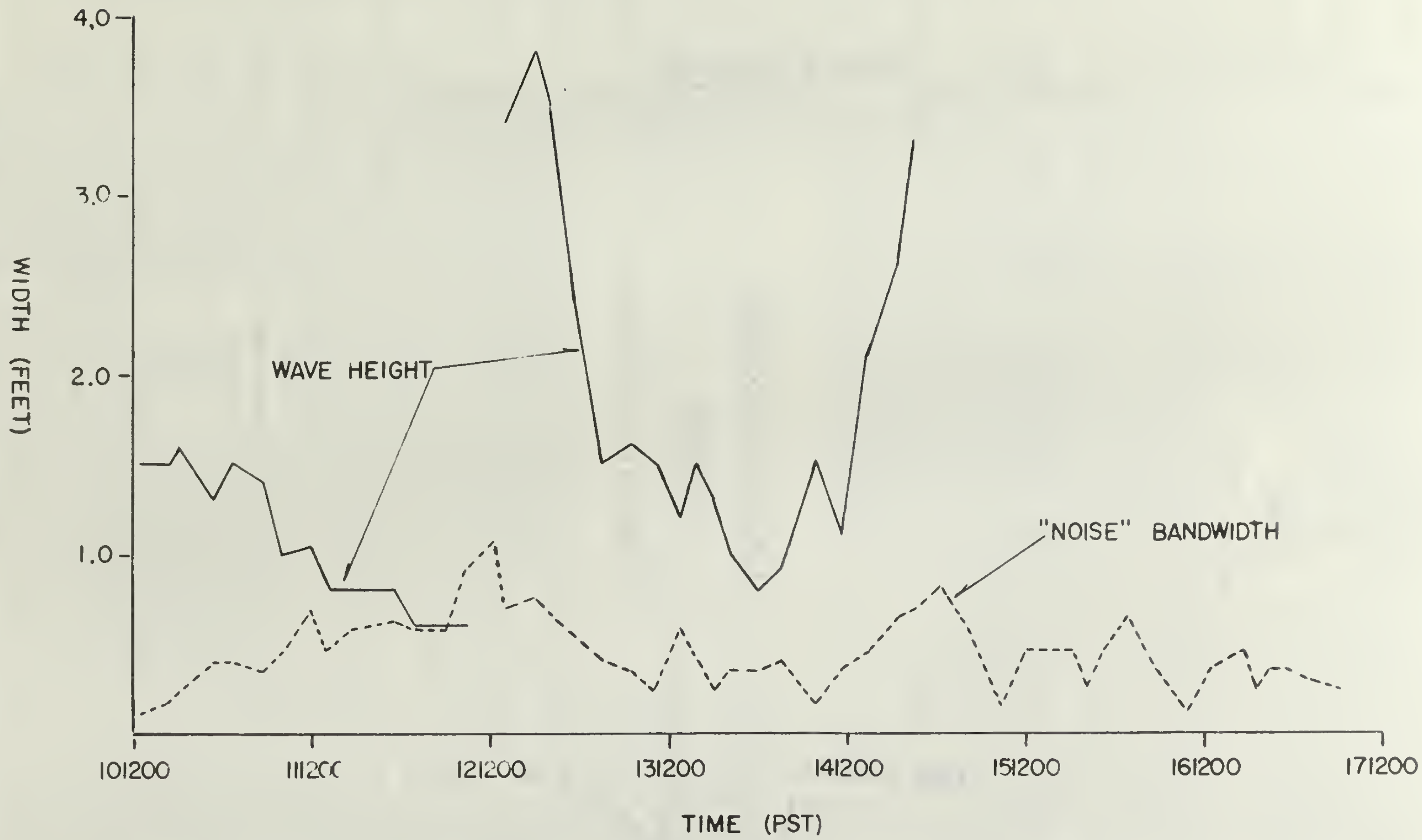


FIGURE 16 "NOISE" AND WAVE HEIGHT OBSERVATIONS

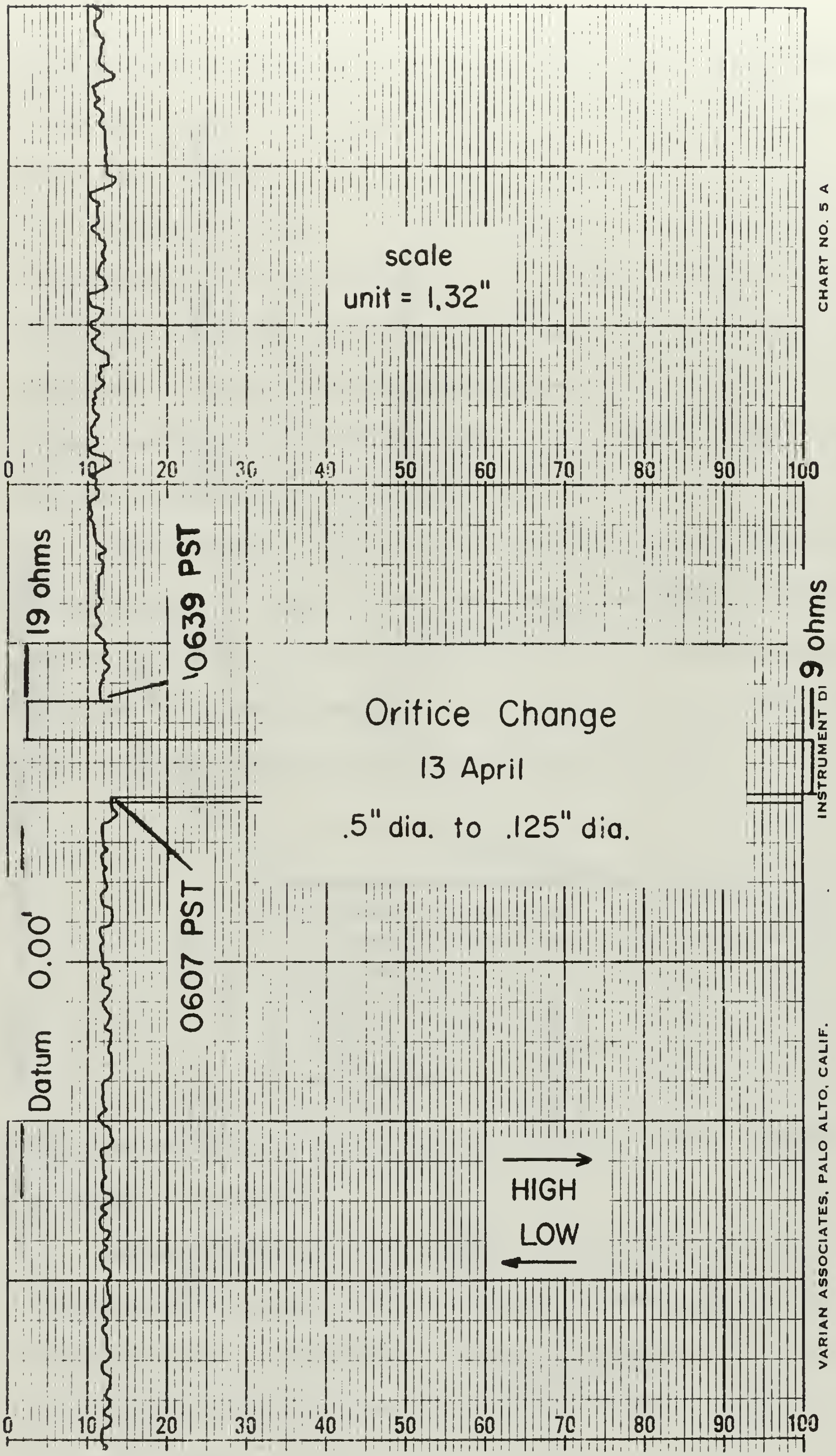


FIGURE 17 ORIFICE CHANGE RECORD

in period and magnitude above the gauge. Comparison of the "noise" band and the wave height data, as plotted in Figure 16, displays a definite correlation between extreme wave heights and maximum "noise" bandwidth. Wave height data after 142100L were not available because of wave recorder malfunction.

As mentioned previously, the orifice diameter was changed during the "in situ" testing period to filter out the higher frequency oscillations being sensed by the resistance gauge. The record obtained before and after this change is reproduced in Figure 17. During the change the recorder speed was 1 inch/minute. The orifice change had no significant effect on the response of the instrument.

7. Conclusions.

The construction and operation of the prototype tide gauge have met the original criteria, except that over the combined calibration data the standard deviation from a straight line is ± 1.494 inches of sea water. However, individual laboratory calibration runs had standard deviations of less than ± 0.1 foot of sea water which satisfies the criteria.

The primary shortcoming of the prototype gauge is the expansion of the mercury reservoir. Therefore, this component part requires future investigation and development.

Reduction of the orifice diameter does not appear to be an effective way to dampen higher frequency water oscillations. The introduction of a viscous fluid within the bellows cavity is being studied. However, information concerning high frequency surface oscillations is often extremely important to other studies and should not be considered a great disadvantage.

Further laboratory testing and field evaluation are necessary before the instrument can be fully applied. However, the prototype constructed establishes the feasibility of the theory and design of this resistance tide gauge.

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Part No.	Rqrd.	Name of Part	Material
1	1	HOUSING	Cast acrylic
2	1	CHAMBER	Cast acrylic
3	4	FLANGE	Cast acrylic
4	2	FLANGE	Cast acrylic
5	3	JOINT	Cast acrylic
6	1	SNORKEL	Extru'd acrylic
7	1	SENSOR TUBE	Extru'd acrylic
8	1	COLLAR	Cast acrylic
9	1	SPACER	Cast acrylic
10	1	FOOT	Cast acrylic
11	1	BASE	Cast acrylic
12	2	PLUG	Nylon
13	1	RING	Cast acrylic
14	1	SUPPORT	Extru'd acrylic
15	1	KEY	Nylon

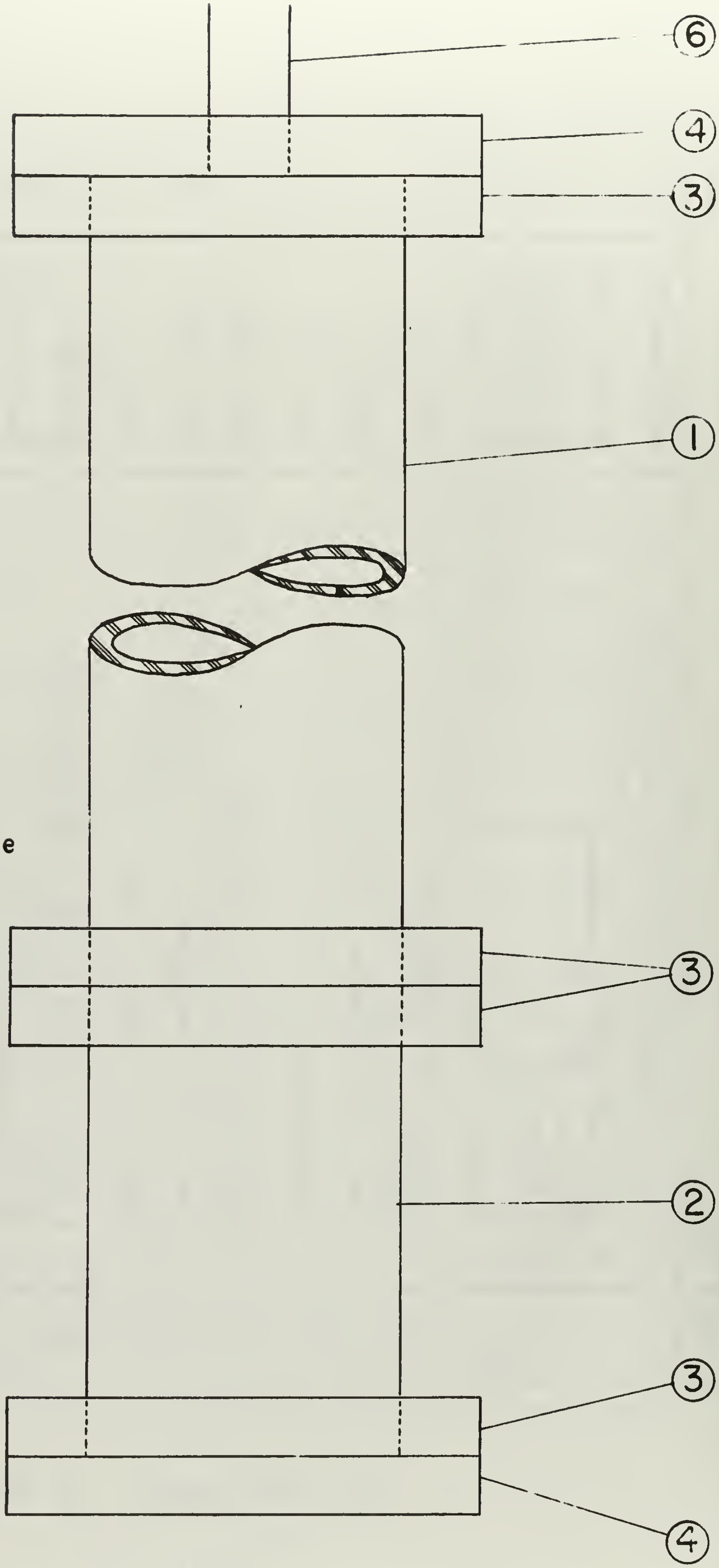
FIGURE 18 GAUGE PARTS LIST

Part No.	Rqr	Standard Parts	Material	Used With
16	24	Bolt 1/4"-20NC-2, 2 1/2" long, hexagonal head	316 Stainless Stl.	3,4
17	24	Nut 1/4"-20NC-2, hexagonal	316 Stainless Stl.	16
18	48	Washer 1/4", flat	316 Stainless Stl.	16
19	24	Washer 1/4", lock	316 Stainless Stl.	16
20	4	Gasket 1/4", 6" diameter	Neophrene	3,4
21	1	Wire, .003" diameter, 36" long	Platinum	7
22	2	Terminal, lug	Steel - Tin	8
23	3	Bolt 6-32, 2" long, round head	Steel - Nickel	7,8
24	3	Nut 6-32, hexagonal	Steel - Nickel	23
25	1	Mercury, technical grade, 1 lb.	Mercury	7
26	1	Bellows, w/base & ring, Snodgrass Mark IX	Neophrene	10
27	1	Fluid, dampening, 300 cc	Distilled Water	26
28	1	Reservoir, mercury	Vinyl	10
29	1	Thread, lacing	Nylon	28
30	1	Cable, shielded, two conductor, 25' long		6

FIGURE 19 STANDARD PARTS LIST

FIGURE 20

HOUSING ASSEMBLY



acrylic weld ----------

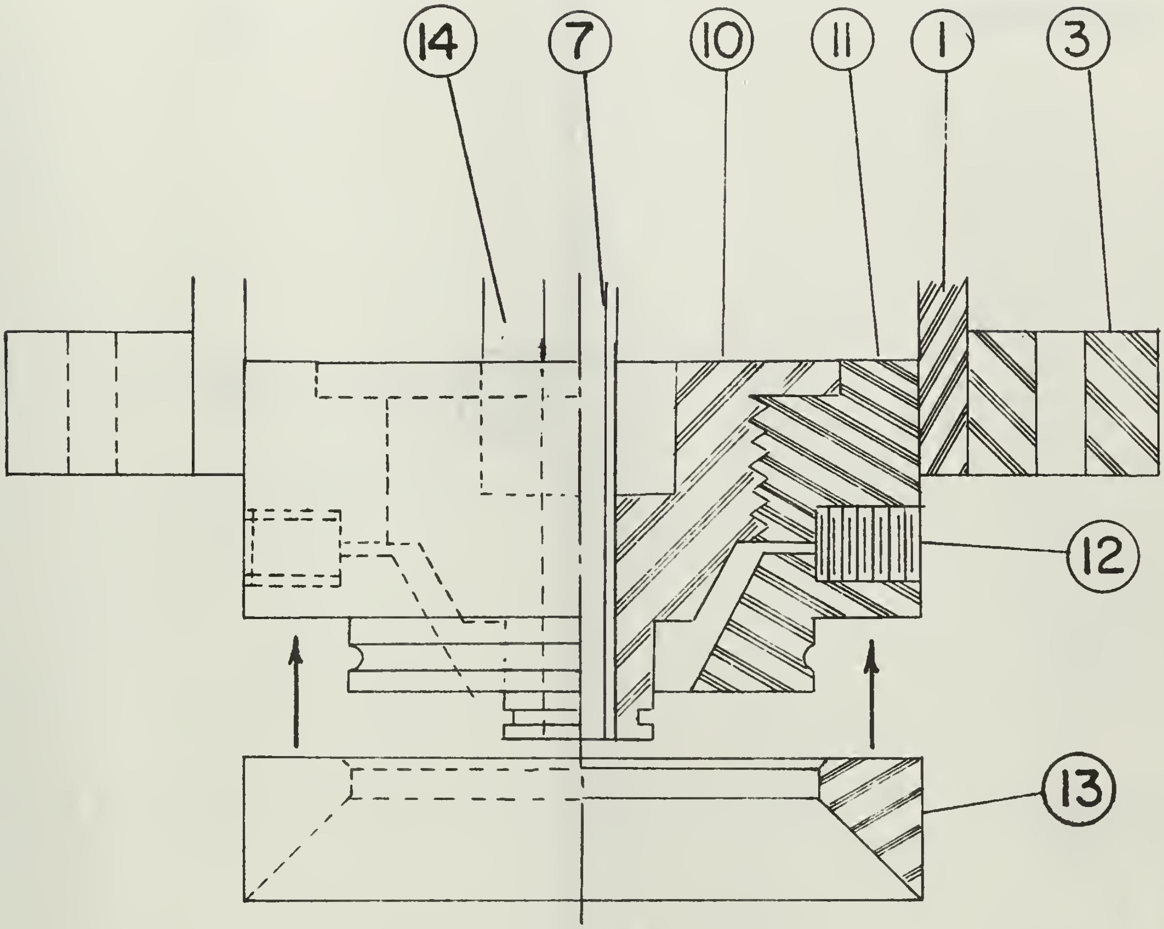
flanges bolted with

316 Stainless hardware

scale 1/2" = 1"

FIGURE 21

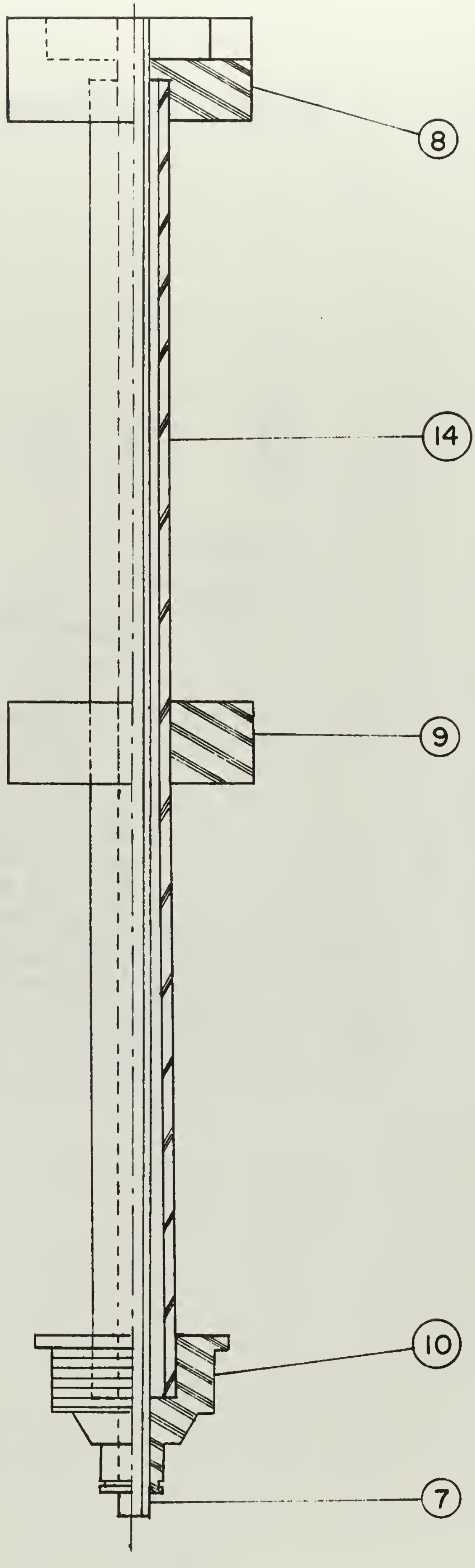
BASE ASSEMBLY



Scale 1" = 1"

FIGURE 22

SENSOR
ASSEMBLY



Scale 1/2"= 1"

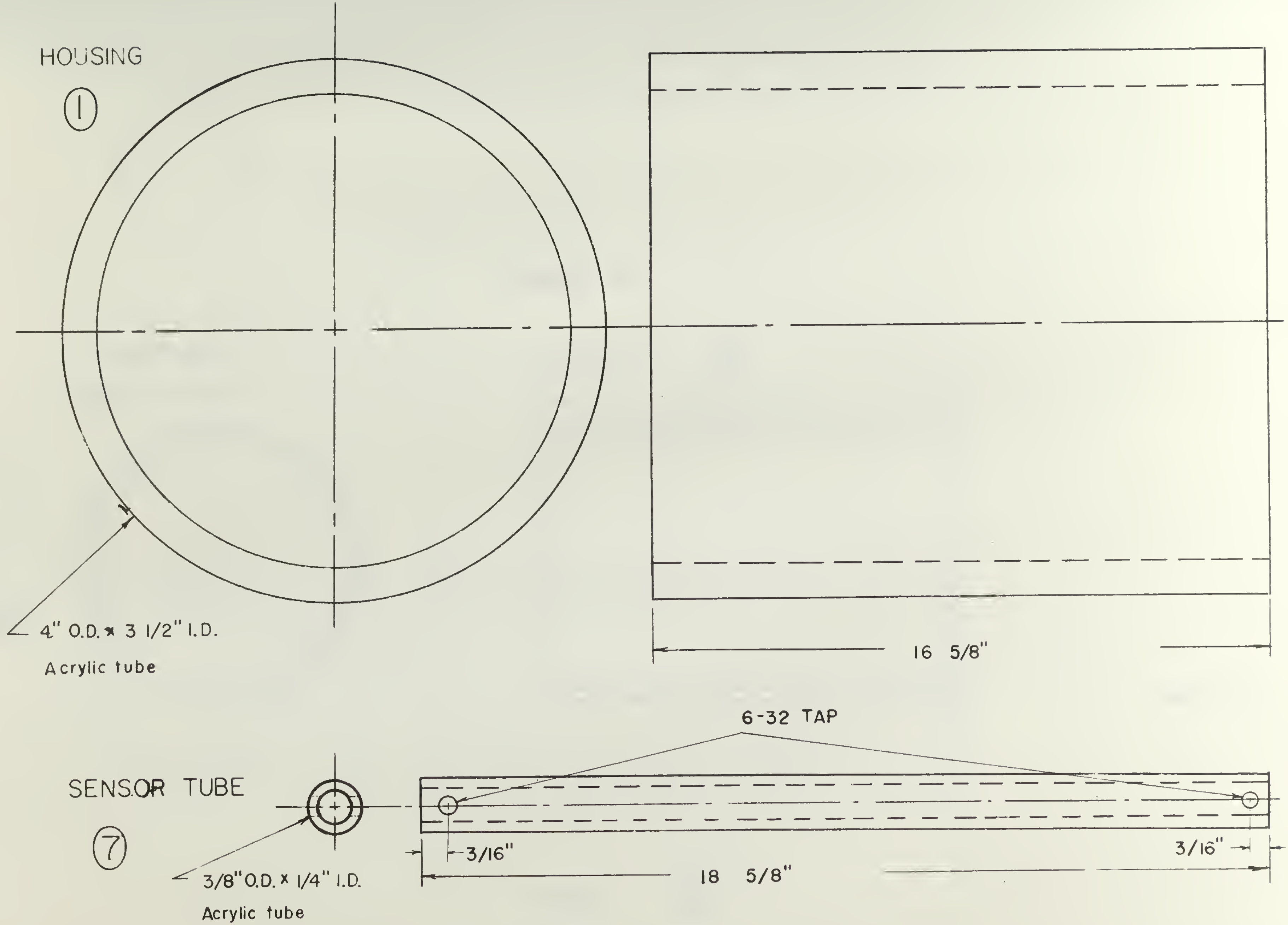

HOUSING
1
4" O.D. × 3 1/2" I.D.
Acrylic tube
16 5/8"
SENSOR TUBE
7
3/8" O.D. × 1/4" I.D.
Acrylic tube
6-32 TAP
3/16"
3/16"
18 5/8"

FIGURE 23

CHAMBER

2

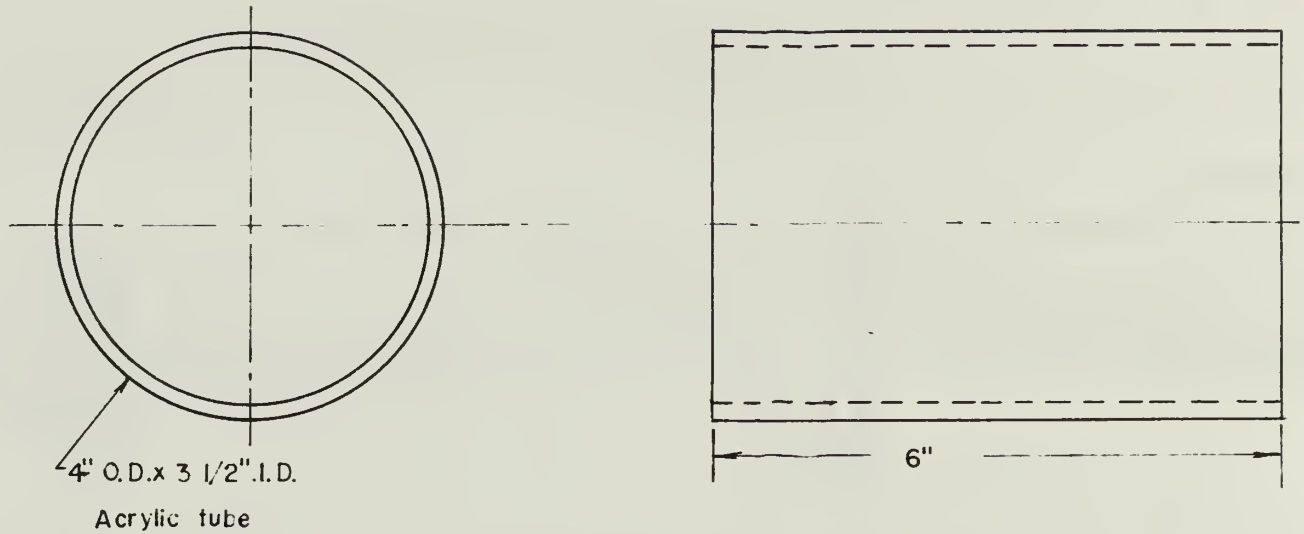


FIGURE 24

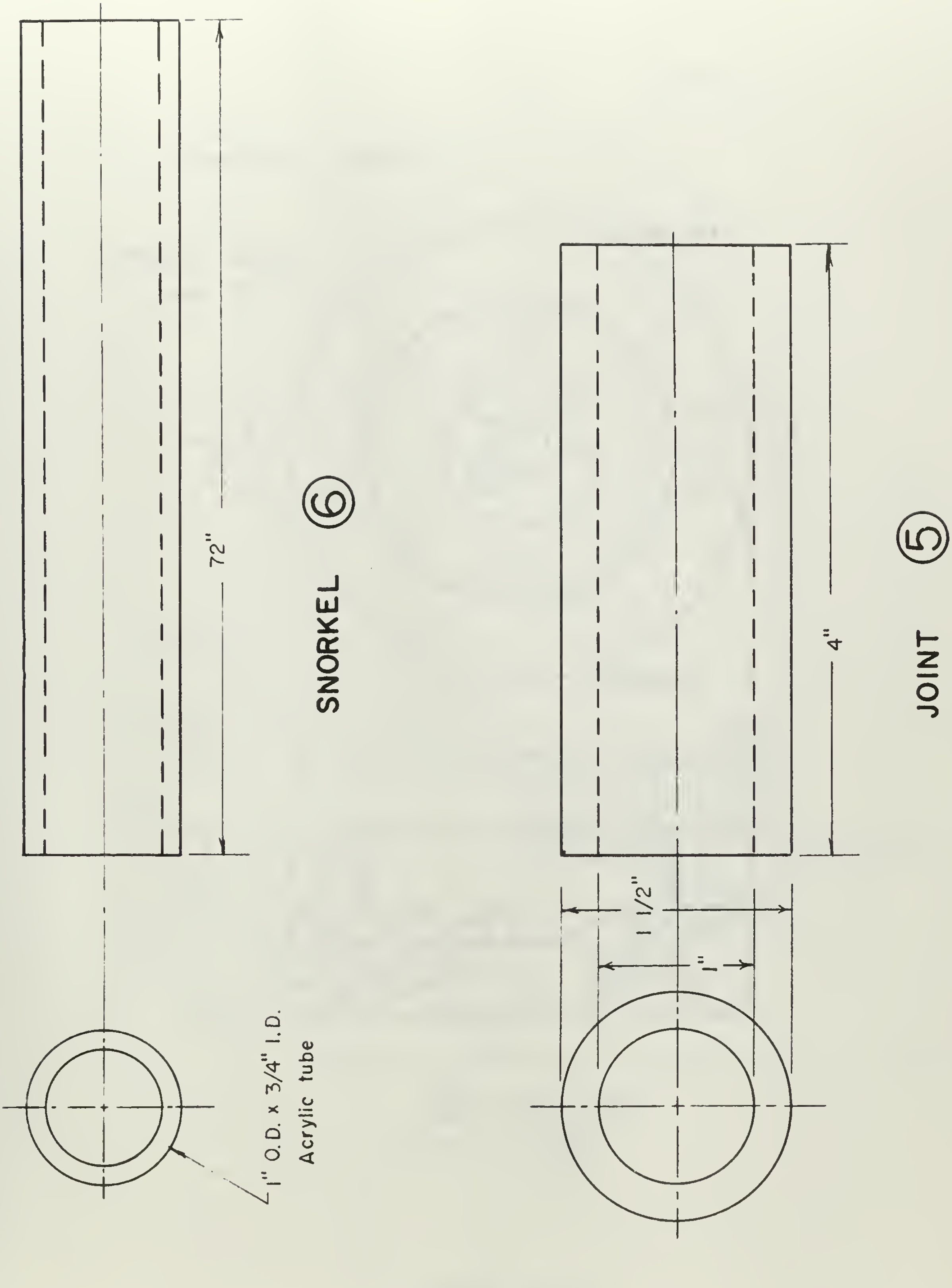
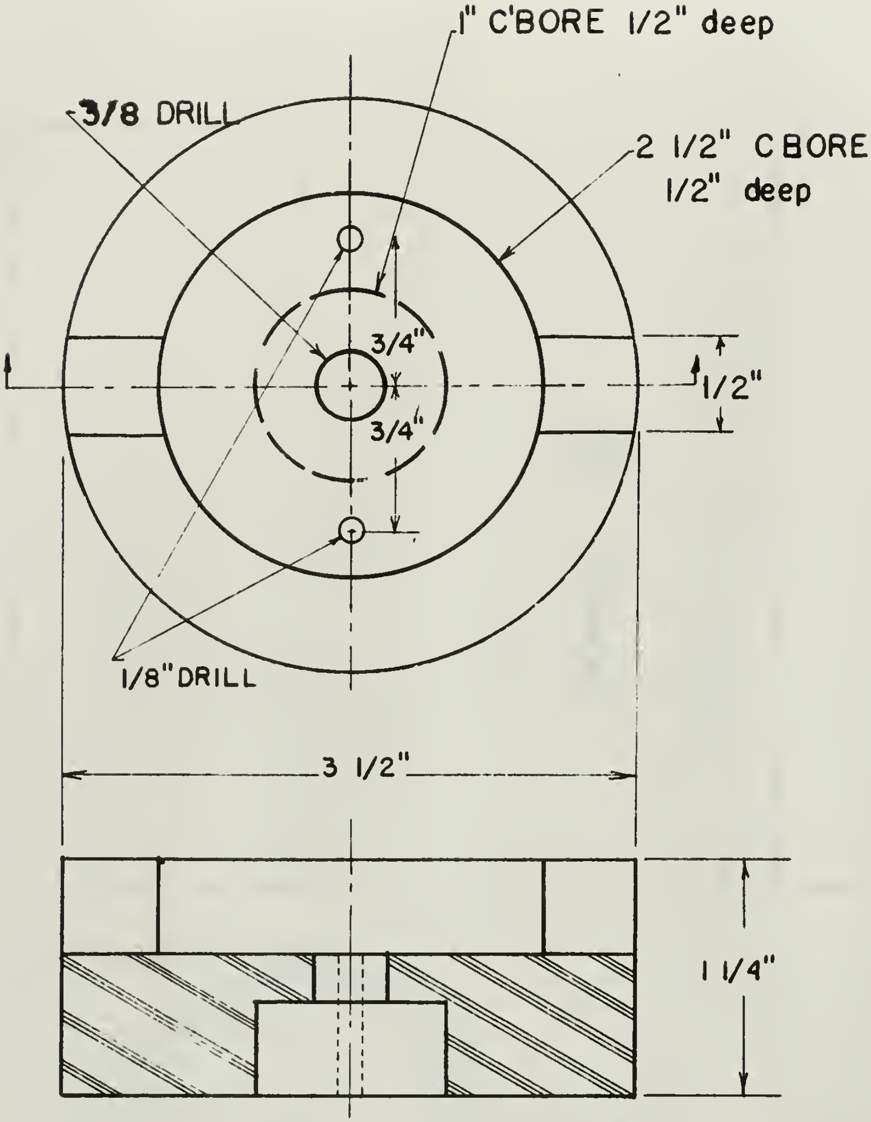


FIGURE 25



COLLAR ⑧

FIGURE 26

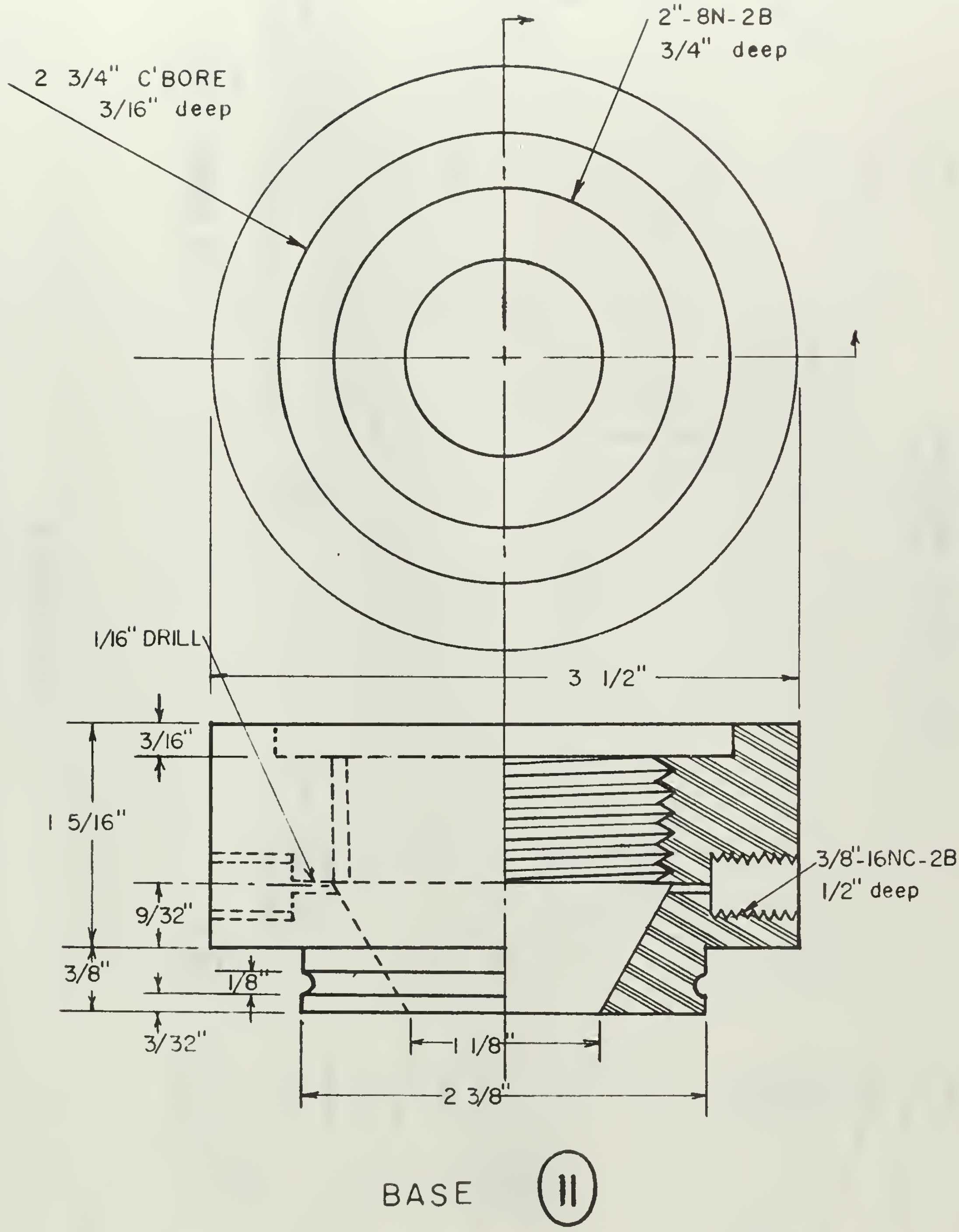

2"-8N-2B
3/4" deep
2 3/4" C'BORE
3/16" deep
1/16" DRILL
3 1/2"
3/16"
1 5/16"
3/8"-16NC-2B
1/2" deep
9/32"
3/8"
1/8"
3/32"
1 1/8"
2 3/8"
BASE
11

FIGURE 27

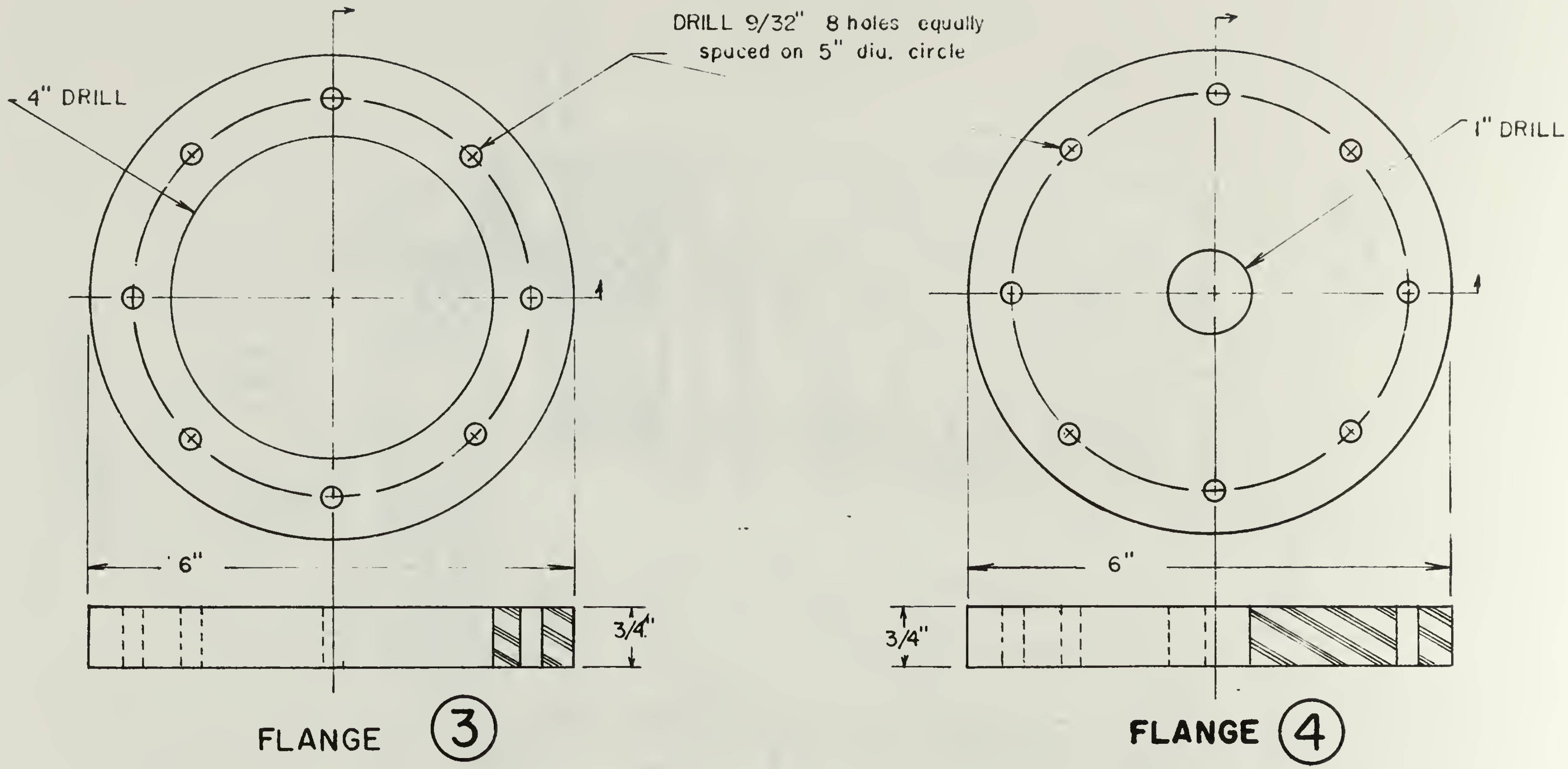
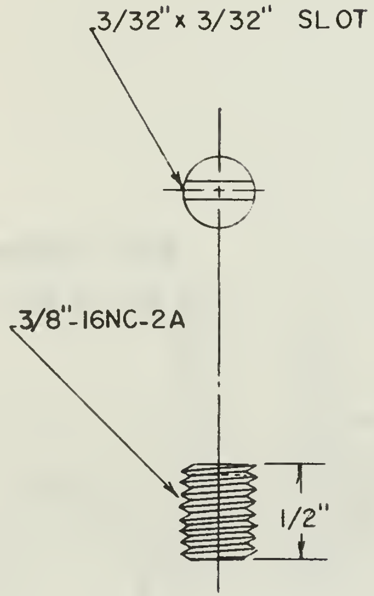
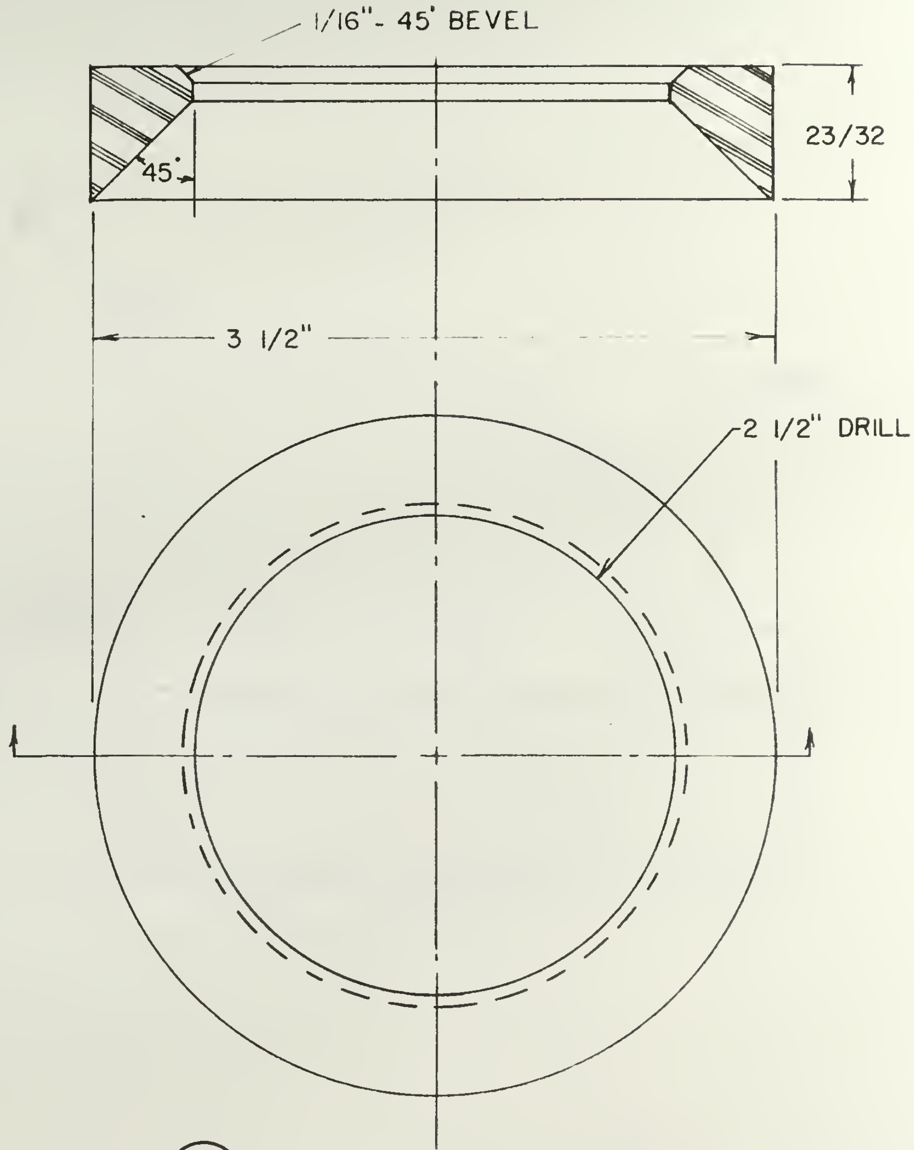

4" DRILL
DRILL 9/32" 8 holes equally
spaced on 5" dia. circle
1" DRILL
6"
3/4"
6"
3/4"
FLANGE 3
FLANGE 4

FIGURE 28



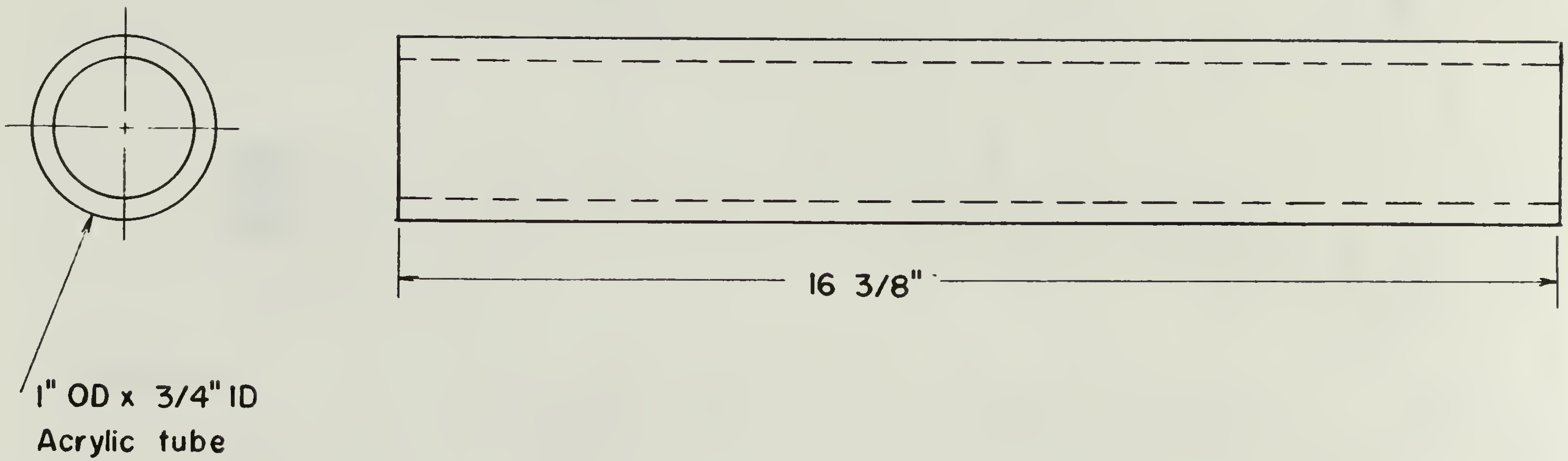
PLUG ⑫

FIGURE 29



RING ⑬

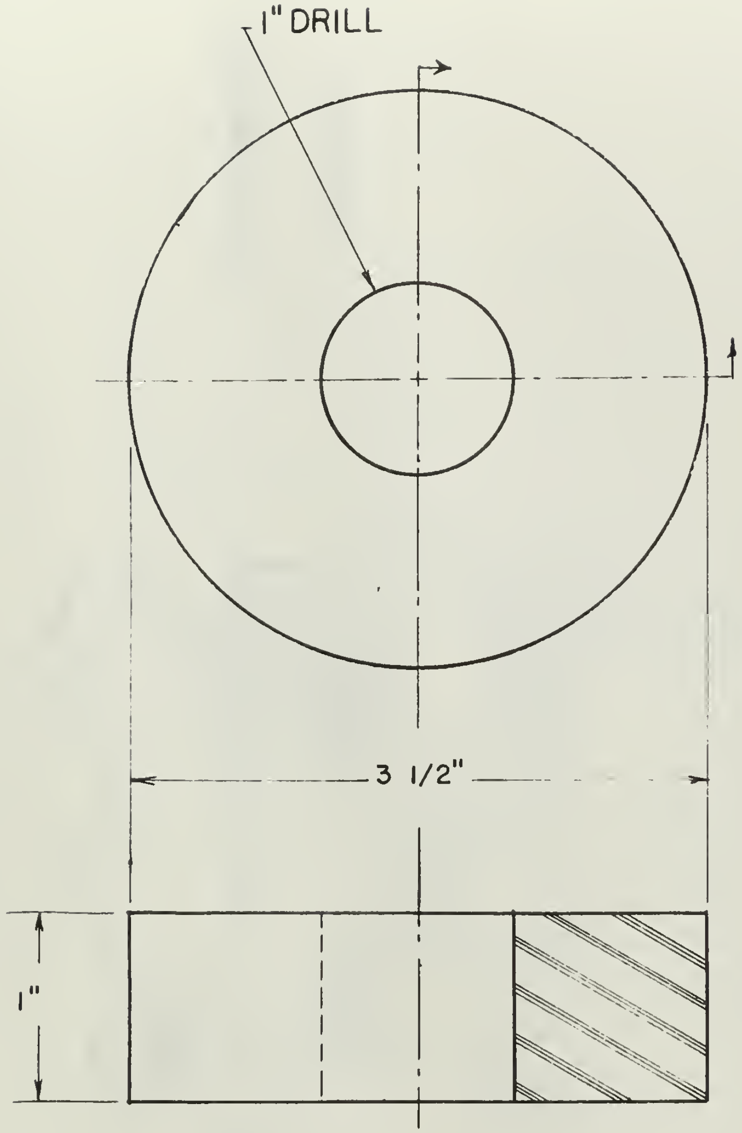
scale 1" = 1"



not to scale

SUPPORT 14

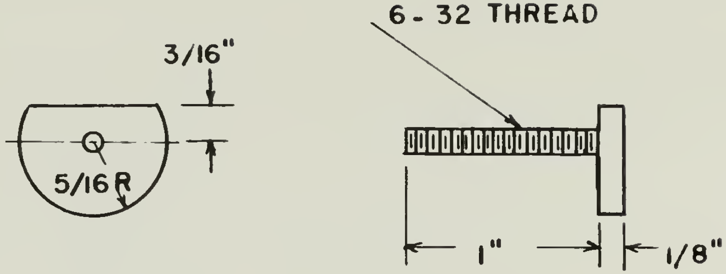
FIGURE 30



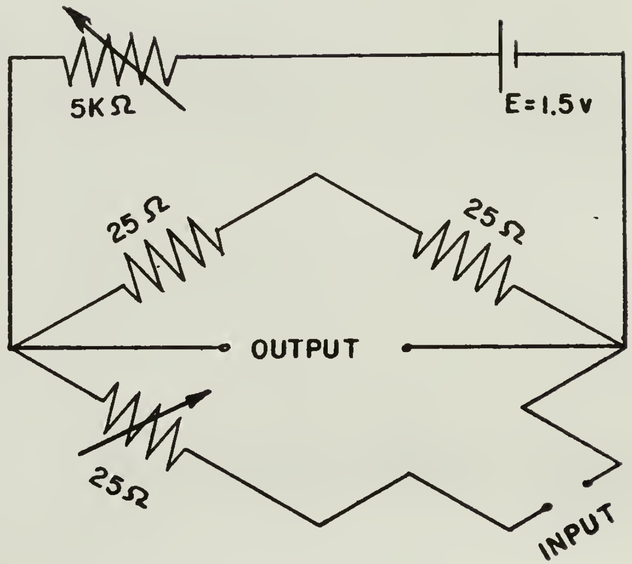
SPACER ⑨

scale 1"= 1"

FIGURE 31



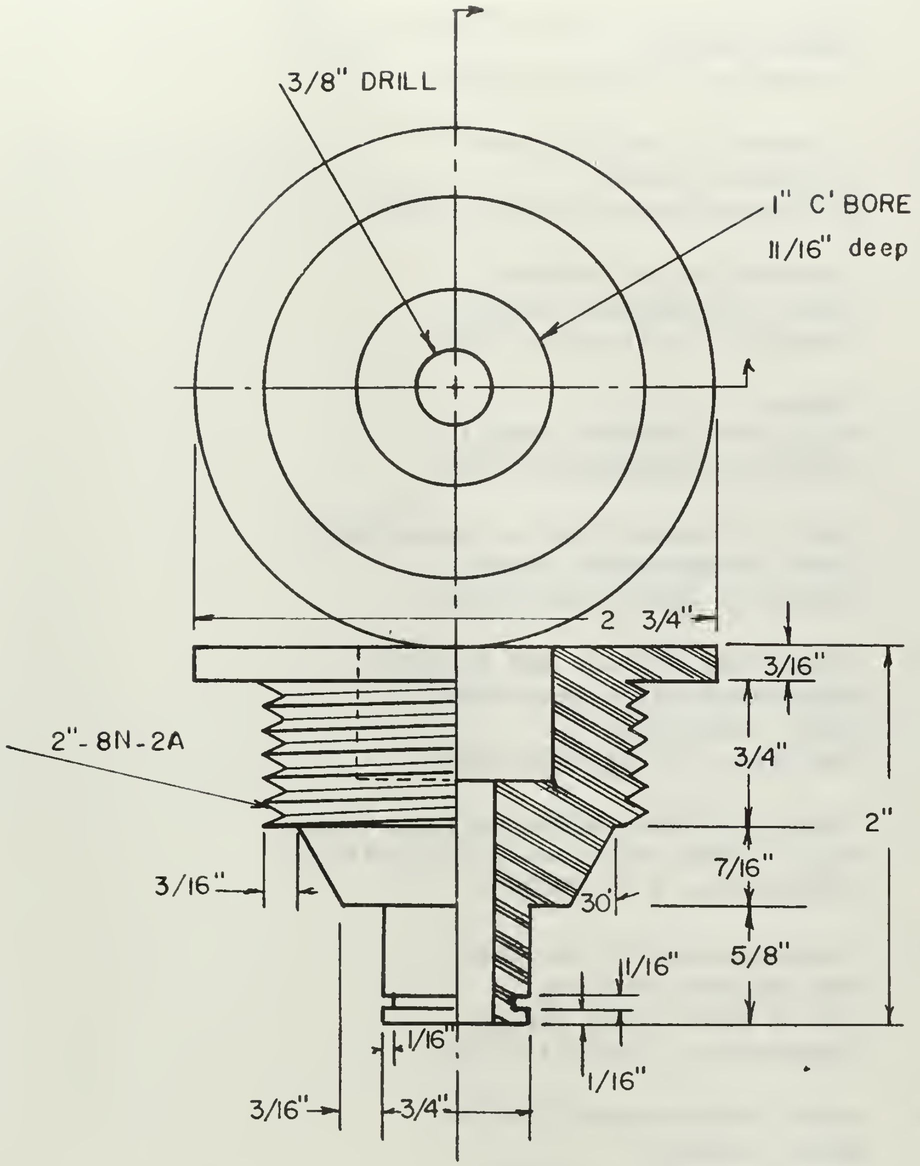
KEY ⑮



BRIDGE

SCHEMATIC

FIGURE 32



FOOT 10

scale 1" = 1"

FIGURE 3.3

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13. ABSTRACT

The design, construction, calibration, and field application of a simple resistance-type tide gauge are presented. The gauge measures coastal water level in relation to an elevation reference. A summary of previously available tide gauges is made with advantages and disadvantages noted.

The gauge sensor consists of a high resistance wire within a mercury-filled capillary. The mercury level in the capillary is pressure-linked to the sea water column and responds to changes of water level over a wide period range. The mercury column height changes the current-conducting length of the resistance wire in the capillary. The change in resistance is, therefore, linear with column height. The resistance element forms one arm of a Wheatstone bridge.

Laboratory evaluation and calibration are described. Recorded field observations of the resistance gauge are compared to the record of a "standard" tide gauge at the same location.

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	ROLE	WT	ROLE	WT	ROLE	WT
Resistance tide gauge Water level measurement Oceanographic instrument						

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